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ON THE SURFACE TEMPERATURE OF THE NORTH SEA AND OF THE NORTH ATLANTIC.

By Professor D'ARCY W. THOMPSON, C.B.
Scientific Member of the Board.

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ON THE SURFACE TEMPERATURE OF THE NORTH SEA AND OF THE NORTH ATLANTIC.

BY D'ARCY WENTWORTH THOMPSON.

It is generally recognised that we cannot hope to understand the ways of life of Fishes and other inmates of the sea, unless we first acquire a sound knowledge of the sea itself and all its physical conditions. With these physical conditions of the sea, the life and habits of the fish are continually bound up. The temperature, the salinity, the contained gases of the sea must be so ordered and regulated as to be in keeping with the fishes' vital needs; as they alter, the fish will be affected for better or for worse; as they vary from place to place, one species or race of fish will tend to make way for another. Abnormal conditions may lead to scarcity, or sometimes to unusual abundance of fish; and such changes as come year by year with the revolving seasons must be in great part the cause of the fish's periodic movements and migrations.

With the exception of the Tides, whose immediate practical importance has led to their being studied with especial care, we know more about the Temperature of the sea, and its variations from place to place and from season to season, than we do about any of the other physical phenomena with which the science of hydrography deals. But even here our knowledge is still far from adequate and far from accurate. In the first place, though we know a great many important and fundamental facts about the temperature of the deeper waters, our knowledge of the seasonal and other fluctuations of these deep-sea temperatures is very limited indeed; and, in the second place, though we know a good deal more about the distribution and the periodic variations of temperature at the surface of the sea, yet, in the narrow seas, such as the North Sea and all our coastal waters, even the surface temperature presents us with problems of very great complexity, and as yet we can by no means claim a complete understanding of all its various phenomena.

In such a phenomenon as Temperature, whose interest lies chiefly if not wholly in its fluctuations, our knowledge grows slowly, and by successive well-marked stages. We learn, to begin with, the average temperature of the sea in some particular localities. As we study it in a larger and larger number of places we come to see the gradual changes, and the underlying laws, which connect one locality with another; till at length (though our points of observation may not be very numerous) we are enabled to map out the mean temperature over a large area of sea, or a long stretch of coast-line. All physical science rests upon this principle of Continuity, this tendency of phenomena to vary in an orderly way, from place to

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place, and from one day or hour to another. While this is one of the most fundamental and familiar of truths to the scientific student, it is still worth while to lay stress upon it. For when the present North Sea investigations were being begun, some twelve or thirteen years ago, we were constantly told by certain persons that we could never by any possibility come to learn the temperature, the salinity, or other physical conditions of the North Sea; for at the best our observations could only be made at places miles apart, and repeated at considerable intervals of time. It was obvious, we were told, that of the temperatures in those miles of water between our chosen stations out at sea, and of the temperatures at those stations on the days when the observer was not there, we should know nothing whatsoever! Now, if this were so, there would be no such thing as physical science; but it is not so at all. There are, of course, degrees of accuracy which are only to be attained by very close and very frequent observations; there are minute fluctuations of all kinds which, if we desire to study them, we must do so by almost microscopic methods. Were we studying, in the utmost possible detail, the distribution of temperature on the land, we should be able to note differences not only between the top and bottom of any little hill, but (as we all know) between one side of a garden and the other. We may put all sorts of detail into a large-scale map which we are unable to show upon a small-scale one. But the minute features of a large-scale map, and the many local variations which it illustrates, are only comparatively small and relatively unimportant phenomena compared with those greater and more general ones which underlie them all, and of which our small-scale map gives us the broad and general picture. The principle of continuity gives us the right to pass from one known point to another, and from a few chosen points to draft the whole configuration of a map. Even in the extraordinarily complicated phenomenon which we call "Weather," where the secondary fluctuations or minor irregularities are exceptionally large, it is still possible to draw, day by day, a "weather-chart" for a country or a continent, from a comparatively small number of observations, made at spots which are far asunder. Through such observations, properly interspaced and not too small in number, a principle of continuity is found to run, which throws the minor fluctuations into the shade.

When we have laid down in this fashion the mean distribution of temperature over a sea or an ocean, the next step in our inquiry is to study the seasonal changes of temperature in a similar way. Our first chart represents the mean or average conditions of the year, more or less approximately; but we next want to know how June differs from December, and any one month from another. To do this we must, of course, multiply our observations, repeating them year after year, for a term of years, and at all seasons of the year, helped all the while by the same principle of continuity. For the changes will be gradual and regular in Time, as we have found them to be in Space, and so we eke out our knowledge, counting upon this regularity or gradation. Even if at some station or other, for example, we have no direct knowledge from observation of the temperature during some particular month, but do possess such knowledge for the months before and for the months after, we may

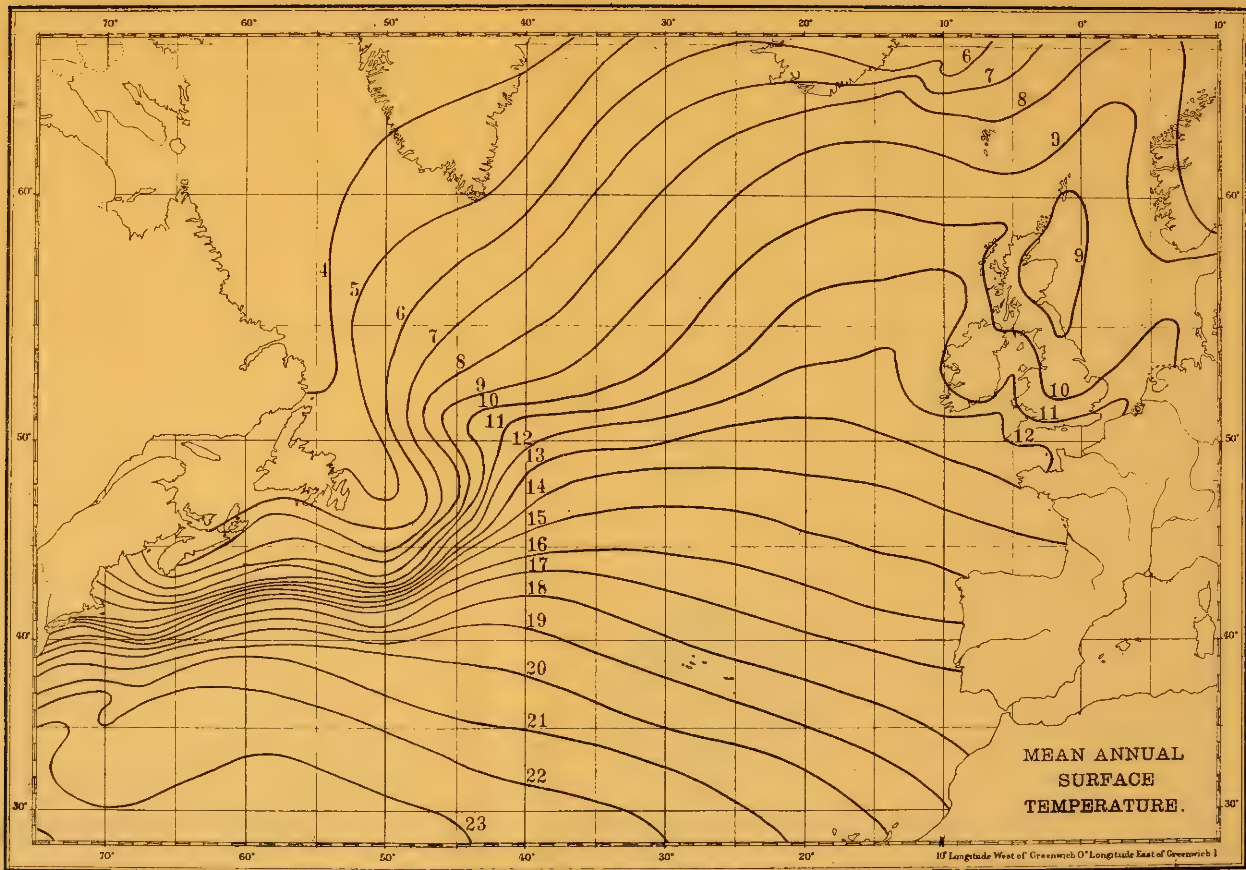

FIG. 1.

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proceed with confidence to "interpolate," to fill in the missing fact or figure in harmony with the others, and so to fill up the gap. It goes without saying, of course, that this procedure of "interpolation" is to be employed with all possible care and caution: it is to be used but not abused; and it must be more and more dispensed with as our work proceeds, as knowledge accumulates, and as we aim at greater and greater accuracy in detail.

Throughout all our study of temperature, or of other physical conditions of the sea, we are on the look out for abnormal conditions, which may help us to understand and to explain such abnormal conditions of fish-life as appear from time to time, and affect seriously the fortunes of the fisherman. History tells us that, among various fishes (the herring in particular and also the haddock and a number of others), there have been great temporary fluctuations, sometimes in the direction of scarcity, sometimes in the direction of extraordinary plentifulness. Such fluctuations were experienced even in days when the toll taken of the stock by man was so small that of itself it could not possibly affect the common stock; and even nowadays, when the catch is multiplied many fold, and is no longer insignificant, we can still in many cases recognise years of plenty alternating irregularly with years of scarcity, and the reasons for this alternation we are bound, apparently, to look for in some abnormal changes of physical conditions. But it is obvious that we have no right to speak of abnormalities, no right to assert that here or there the sea is warmer or colder, more or less salt, than usual, until we have a very thorough knowledge indeed of the *normal conditions*, and of the periodic changes which are a part of the normal phenomenon. And so it comes to pass that the very kind of knowledge which, for our practical ends, we most desire to have (namely, the knowledge of *abnormal* conditions), is bound to be postponed till we have prepared the way for it by years of work, employed in gathering knowledge which is of little practical utility in itself, but which is the indispensable preliminary step to that other knowledge which we have every hope of turning to practical account.

Among other charts and diagrams, the present paper contains a series of twelve charts, in illustration of the mean or normal temperature of the North Sea and of the other waters round our coasts, for each month of the year. For several years past I have had these charts in preparation, and I have more than once been about to publish them, with such additions or corrections as I was able to make for the time being. But again and again I put the task aside, waiting for still more information. Now, however, it seems to me to be time to publish these charts; not that they are to be considered in any way complete or final, but simply because they now give, as it seems to me, just such a representation of our seasonal surface-temperature phenomena as may usefully serve a temporary purpose, and be gradually improved and corrected by those workers who are making a special study of our sea temperatures in particular areas.

The observations on which this paper and the accompanying charts are based are drawn from many sources, of which the following are the chief:

1. The mean surface temperatures for the Atlantic, in the pos-

session of the Meteorological Office, and collected during many years by the captains of many Atlantic liners. These data have been entrusted to me by the Marine Superintendent, Captain Campbell Hepworth, R.N., C.B.

2. For the Northern Atlantic, north of 60° N., I have relied mainly on the data, also derived from captains of ocean-going liners, which are set forth from year to year and from month to month, in the charts published by the Danish Meteorological Office in the Nautisk-Meteorologisk Aarbog. I have extracted and averaged these data from the annual reports for the years 1903–1913.

3. For the North Sea itself, I have depended almost wholly upon the observations collected for us during the past twelve years by various captains of passenger vessels trading between British and continental ports. These observations have been frequently dealt with in our North Sea Investigation Reports, and I have now collated and averaged the whole of the available material in the hands of the Fishery Board. I am well aware that other such observations are in existence elsewhere, which are not yet published, and which I have not been able to incorporate here.

4. A very important contribution to all such work as this is contained in Dr. H. N. Dickson's paper, published in 1899, on "The Mean Sea Temperature of the Surface Waters of the Sea round the British Coasts." * This paper contains, among other matters, the mean monthly sea temperatures for over sixty stations round the coasts of Great Britain and Ireland, based on observations made at various lightships and coastguard stations during a considerable, but varying, number of years. These data (transferred to the Centigrade scale) I have reprinted at the end of the present paper.

Some years ago, by the kindness of the Director of the Meteorological Office, I was entrusted with the more recent records from the same stations, and I began the task of summing and averaging the observations with a view of bringing the whole mass of temperature statistics up to date. This task, however, I soon gave up, for it was extremely laborious, and the addition of a few years to the periods dealt with by Dr. Dickson gave mean values which were not appreciably different from his own. I came, accordingly, to the conclusion that the number of years dealt with by Dr. Dickson was, in general, long enough for the determination of means from which very useful deductions could be drawn. But it is now sixteen years since Dr. Dickson published his results, and there is no doubt that, wherever observations have been continued steadily during all these sixteen years, it would be well worth while to revise the whole work and to make out a new table of mean values.

5. For the English Channel I have received from Mr. E. C. Jee, of the Board of Agriculture and Fisheries, a most useful series of Mean Monthly surface temperature values, obtained during recent years on three cross-channel passenger routes.

6. Lastly, I have obtained from various sources data for the surface temperatures at a number of continental stations. The most important of these are the following: (*a*) Observations from eight Norwegian lighthouses for the period 1874–1903, prolonged in some cases to 1912. These were prepared by Mr. Axel S. Steen, of

* *Quarterly Journal of the Royal Scottish Meteorological Society*, xxv. pp. 277–302.

the Meteorological Institute of Christiania, and sent to me through Professor Helland Hansen. (*b*) Similar data from a number of Danish lightships and lighthouses, as recorded year by year in the Nautisk-Meteorologisk Aarbog. (*c*) Similar data from four Dutch lightships, sent me by my friend the late Professor Wind of Utrecht.

The methods which we are accustomed to use in dealing with our large collections of Temperature statistics, in order to bring out the main lessons which they contain, have been described at various times in the Reports of our North Sea Investigations, and especially in a paper by me on "Some Methods and Results of Hydrographical Investigation," published in 1907, in our second volume of Reports. It is not necessary, therefore, to deal at any length with the matter here.

What we are at present mainly concerned with is to show (1) the *mean* conditions, as determined over a long series of years; and (2) the main *annual* fluctuation, as it is expressed by the mean temperature conditions which are characteristic of each of the twelve months of the year. Besides these, there are many other important phenomena of temperature which, in due time, deserve consideration. For instance, there are minor but still regular fluctuations, such as those between night and day; there are interesting phenomena connected with the relations between the temperature of the sea and that of the air; and of very great interest and importance are the fluctuations from one year to another, which are apparently irregular, but in which it seems by no means impossible to discern some orderly sequence, underlying the apparent irregularity. These, and many other phenomena besides, are matters for special inquiry, after the mean, or mean annual, phenomena have been sufficiently investigated and ascertained.

We begin, then, by ascertaining for each station, and for the whole period over which our observations extend, the Mean Annual, and the twelve Mean Monthly temperature values; and these we may set straightway down upon the chart, and draw in each case, as best we can, the isotherms, or lines of equal mean temperature, between the corresponding points.

In many cases, and especially where we are dealing with a continuous line of observations, or of means drawn from observations in small contiguous areas, we may with advantage employ a more systematic method of interpolation. For instance, if we take the Atlantic Temperature observations collected by the Meteorological Office, we find these averaged out for small areas of the ocean, each one measuring two degrees of longitude by two degrees of latitude; the mean temperature for each small area being determined to the nearest whole degree Fahrenheit. If we take any one linear series of these means across the ocean, along some one degree of latitude, or some one degree of longitude, and plot the successive values on squared paper, we get a broken line through which it is not difficult (as a rule) to draw a smooth curve. From this smooth curve we can read off the approximate mean temperature at any point, or the point which approximately coincides with any particular temperature; we may accordingly use it to determine *the position of our isotherms.* Thus, in the following

figure (Fig. 1A), we have, in the first place, the uneven line which is directly drawn from our data of Mean Temperature—relating, in this particular case, to a strip across the Atlantic, east and west, between lat. 40° and lat. 42° N. Superimposed upon it is a smooth curve, which must approximately represent that actual variation in temperature, which the recorded numbers and broken line express not very accurately, but as nearly as whole numbers can. In short, the drawing of this smooth curve tends to bring out of our recorded

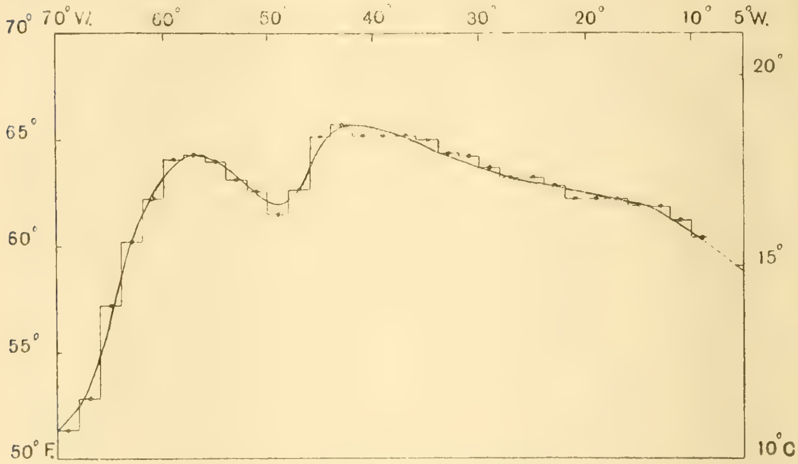


Fig. 1A.—Mean surface-temperature in the North Atlantic, on the parallel of 41° N. lat.

data a little more than they obviously, but not more than they implicitly, contain. Lastly, from the smooth curve, we can now read off the position of the isotherms, that is to say, the points in latitude where the curve crosses the ordinates indicating 50°, 55°, or 60° Fahrenheit as the case may be. Moreover, it is obvious that, by using another scale of temperature, we may, without redrawing our curve, read off the position of our isotherms according to degrees Centigrade, or any other temperature scale we please. The result of the whole process is shown in the annexed Table.

(1) Means of observed Atlantic Surface-temperatures, between Lat. 40° and 42° N.

Long. W. .	70° 68°	68° 66°	66° 64°	64° 62°	62° 60°	60° 58°	58° 56°	56° 54°	54° 52°	52° 50°	50° 48°	48° 46°	46° 44°
Temp. F. .	51·4	52·8	57·2	60·1	62·2	64·0	64·3	64·0	63·1	62·5	61·5	62·6	65·1
Long. W. .	44° 42°	42° 40°	40° 38°	38° 36°	36° 34°	34° 32°	32° 30°	30° 28°	28° 26°	26° 24°	24° 22°	22° 20°	20° 18°
Temp. F. .	65·7	65·2	65·2	65·2	64·9	64·4	64·2	63·6	63·2	63·2	62·8	62·2	62·1
Long. W. .	18° 16°	16° 14°	14° 12°	12° 10°	10° 8°								
Temp. F. .	62·1	61·8	61·7	61·1	60·2								

(2) Temperatures interpolated from the above data, along the parallel of 41° N.

Long. W. .	70°	65°	60°	55°	50°	45°	40°	35°	30°	25°	20°	15°	10°	(5°)
Temp. F. .	51·1	55·7	63·4	64·0	62·2	64·8	65·2	64·7	63·9	63·0	62·2	61·9	60·7	(58·7)

(3) Interpolated positions (in Long. West), along the parallel of 41° N., which are intersected by the respective Isothermal Lines (Fahr. and Cent.).

65° F.	44·7	37·1			18·5° C.	44·1	39·0		
64° F.	58·3	55·0	45·9	30·8	18·0° C.	45·6	33·2		
63° F.	60·8	52·4	46·4	25·2	17·5° C.	59·8	53·5	46·2	28·0
62° F.	62·1	49·4	48·2	15·3	17·0° C.	61·4	51·2	46·6	22·7
61° F.	63·0	9·8			16·5° C.	62·4	14·0		
60° F.	63·6	(7·5)			16·0° C.	63·1	10·4		
59° F.	64·0	(6·0)			15·5° C.	63·7	(8·5)		
58° F.	64·2	(2·0)			15·0° C.	64·0	(6·2)		
57° F.	64·5				14·5° C.	64·2	(2·0)		
56° F.	64·9				14·0° C.	64·4			
55° F.	65·4				13·5° C.	64·8			
54° F.	66·1				13·0° C.	65·2			
53° F.	67·0				12·5° C.	65·7			
52° F.	68·2				12·0° C.	66·5			
51° F.	70·2				11·5° C.	67·4			
50° F.					11·0° C.	68·7			
49° F.					10·5° C.	70·3			

It is of very considerable importance that by this method we can obtain the results which we are seeking in any particular scale (*e.g.* Centigrade) without converting our whole data from the one scale to the other; not only is much time saved, but we avoid the many opportunities for inaccuracy which beset us in converting a long series of *round* numbers from one scale into another; for experience shows that we are apt to get into difficulties in such a process, whether we convert the round numbers of one scale into round numbers in the other, or whether (with an appearance of greater, but only spurious, accuracy) we convert the round numbers of the one scale into precise decimal equivalents in the other.

After we have followed out the process here described for every degree of latitude of which we have information, we may then at once lay down upon our chart, not the actual observed temperatures, but simply the ascertained positions where the isotherms cross the parallels of latitude; and these points are then immediately connected up, so as to give us the complete isothermal lines. It will usually be well worth while to repeat the whole operation in the other direction, taking now the serial temperatures along each meridian. And the two charts which we thus obtain, one from the fluctuations in latitude and the other from the same fluctuations studied in longitude, will materially help to check and correct one another.

But we have yet another check which we may with advantage apply, in the case of our Monthly Mean Temperatures. Our twelve monthly charts (which we may suppose that we have now drawn) show twelve phases of one common phenomenon, throughout which everywhere a principle of continuity runs. We shall expect the temperature distribution in each month to be in harmony with that of the preceding and with that of the succeeding month; and if such harmony is not apparent in our charts, the lack of it may perhaps make us aware of some new and unexpected phenomenon, but is on the whole much more likely to reveal to us some error or imperfection in the systems of isotherms which we have drawn. Accordingly, we proceed to construct a series of isopleth diagrams, such as those in Figs. 25 to 30, each diagram showing the temperatures along one

particular line in space (say longitude or latitude) for all the twelve months of the year. Working with such data as are available in the present case, we usually find that, in making such an isopleth diagram from the twelve sets of data furnished by our monthly charts, the points are found to be on the whole very concordant, and the drawing of our isopleth lines is easy enough; but at the same time a little further smoothing is in most cases necessary. And after this is done, we may once more go back to our isotherm charts, and make such slight alterations upon them as our isopleth diagrams in turn suggest.

Before we leave this part of our subject, it is worth while to call attention to a certain difficulty which constantly besets us in the making of charts for the narrow seas, such as the Channel or the North Sea, from such data as we have to deal with. These data are of two kinds—data from shore stations and data from observations at sea. On the whole the shore data, from observations made at lighthouses, harbour stations, or inshore light-vessels, are the best we have, for they have been made daily, or even oftener, over long periods of years; from these inshore observations alone we can draw very fair temperature charts for our whole British area, and even, with the help of similar continental observations, we may, by interpolation and extrapolation, continue our isotherms across the sea. But while such charts would be found to correspond very fairly well, in a general way, with those which we draw from our actual observations at sea, there is always a very great difficulty in bringing the two sets of observations together in their minuter details. The inshore temperatures have features of their own; neighbouring shore stations may differ much from one another in their proximity to large rivers or in other ways; and, as we shall see presently, proximity to land has a very marked effect upon the sea temperatures, and this effect is apt to be very different at one season from another. Now, as what we are anxious to understand and to represent upon our charts is not the shore temperature but the general surface temperature of *the open sea*, it follows that a great part of our available material, and a part which in other respects is the most trustworthy that we possess, is ill adapted for our particular purpose. The differences are not of great magnitude, and we can overcome the difficulty, more or less completely, in various ways. But the fact remains that it is not possible, without a certain amount of "smoothing" or averaging, to draw systems of isotherms which shall clearly illustrate our main temperature phenomena, and which shall keep with equal closeness to the data furnished by our inshore and our offshore observations.

It may seem at first sight that these successive manipulations of our original data must lead us further and further away from such accuracy as the actual observations contained. But this is by no means so. We are not dealing, as we sometimes profess to do in a laboratory experiment, with a set of data each one of which is as "a nail in a sure place." On the contrary, we are dealing with a vast mass of figures, each one of which is only an approximation, and not even a very close approximation, to a true statement of the mean temperature at a certain place and time; and it is in the interconnected web of all these approximations that the truth which we are seeking lies. The more, then, that we can associate and correlate

together our data, over continuous lines in space or continuous periods in time, the better shall we discern *the general trend* of our phenomena, and the better and more effectively will each one of our numerical values be checked, tested, and interpreted by the conjoint testimony of all its neighbours.

Let us consider for a moment the various phenomena which our subject involves, and the various kinds of diagrams which we may draw in illustration of them. We are dealing with Temperature, in relation to Space, and in relation to Time; and Space is for our present purpose space of two dimensions only, for we are only dealing with the temperatures of the *surface*, and not those of the depths of the sea. We have therefore four "dimensions" to deal with, viz. (1) Temperature, (2) Time, and (3, 4) Space in latitude and longitude, or in any other two correlated directions that we please. Now any system of diagrammatic representation that we can make upon a sheet of paper is practically confined to two or to at most three dimensions, the two variables corresponding to the ordinates and abscissæ of an ordinary diagram on which we plot a curve, and the third variable being introduced when, upon our system of co-ordinates, we superimpose a system of "contour-lines" or "isopleths." We must use, accordingly, more than one system of diagrams before we can represent and correlate the phenomena of four dimensions with which we have actually to deal.

The chief types of diagram which suggest themselves as useful, whether two-dimensional or three-dimensional, are the following.

Our two-dimensional diagrams are meanwhile limited to those in which (*a*) we plot Temperature against Time, or (*b*) Temperature against some one dimension in space; for instance, when (plotting temperature against time) we draw the annual curve of temperature, say, at Dundee; or when (plotting temperature against space or distance) we draw the curve of mean temperature between Leith and Hamburg.

These two types of two-dimensional diagram we may convert into three-dimensional diagrams, by superimposing additional Temperature curves upon the one already drawn; for instance (*a*) by using our first diagram for the seasonal fluctuations at several stations, *e.g.* Aberdeen, Dundee, Leith, etc.; or (*b*) by introducing the element of time into our second diagram, and fitting into it separate temperature curves for the individual months.

(*c*) The commonest of our three-dimensional diagrams is that in which we first plot latitude against longitude in space, or in other words, draw an ordinary map or chart of a portion of the earth's surface; and then plot, over this two-dimensional diagram, the variations of temperature, in the form of isotherms or contour-lines. This method of representation, first introduced by Humboldt, gives us what we ordinarily call a "temperature chart"; but observe that this temperature chart is, and can be, only for one epoch of time. It may be for the average temperatures of the year, or it may be for the mean of some particular month; but it cannot show the succession of phenomena from month to month. To show this, that is to say, to introduce a variation in time, we must sacrifice one of our other dimensions. We cannot here sacrifice Temperature, for that is the

whole object of our inquiry. But we may sacrifice one dimension of space or another, say latitude or longitude; and we then get that diagram of Temperature contoured against Time and Linear Distance, which we are in the habit of speaking of as an "isopleth" diagram. All of these various types of diagrams are very simple, and all are now in frequent use.

Besides such diagrams as these, which all deal with actual Temperatures, it is at times very useful to employ another series which represent Anomalies, or differences of temperature, as compared with some standard mean. This most instructive method of indicating climatic abnormalities was introduced, some sixty years ago, by the great German meteorologist Dove.* For instance, (*d*) instead of showing the actual temperatures, say, in the month of January, along some particular meridian or parallel of latitude, or some other line or route across the sea, it is often instructive to represent these same data in the form of differences from the mean temperature of the year, as this mean temperature in turn varies from point to point. Or, in like manner (*e*), instead of showing the mean temperature of the sea as it varies along some meridian, say that of 5° E. in the North Sea, it may be extremely instructive to represent the same data in the form of differences from the corresponding phenomena along some other meridian, say in the open ocean. Some use of these methods will be made in the following pages.

Lastly, in dealing with the periodic phenomena of the year, it is of the highest utility to deal with them according to the methods of elementary Harmonic Analysis, as I have more than once explained in previous Reports. The temperature changes which follow the seasons at any one particular spot are of the nature of a *wave*, or sine-curve; and this wave is characterised by three features, or numerical "constants." It is a fluctuation about a certain Mean Temperature, and this phenomenon we have already, so far, considered. Secondly, the fluctuation or "wave" has a certain "amplitude," or regular amount of rise and fall. This we shall usually deal with in the form of the "half-range"; that is to say, not the whole amplitude of the wave, but the average rise from the mean to the summer maximum, or the average fall from the mean to the winter minimum; and we shall find that this phenomenon of Range or Amplitude often varies according to locality after a very different fashion from the variations in mean temperature. Again, the seasonal wave of temperature has a definite relation to Time, a definite epoch (on the average) at which the maximum and minimum are reached and the fall or rise begins. This date, corresponding to the so-called "phase" of the sine-curve, will also be found to vary from place to place according to its own proper laws.

This method "of substituting the separate consideration of separate terms of the complex harmonic function for the examination of the whole variation unanalysed" was first employed by Lord Kelvin, in one of his early papers.†

* *The Distribution of Heat over the Surface of the Globe.* London, 1853.

† "On the Reduction of Observations of Underground Temperature; with Application to Professor Forbes's Edinburgh Observations, and the Continued Calton Hill Series," by Professor William Thomson, *Trans. R.S.E.*, xxii. pp. 405–439, 1860.

Like most other "waves" with which physical science has to deal, the seasonal wave of temperature is not a simple wave, but a main wave with which other smaller oscillations are mixed up; and we can analyse these, as in the case of a musical note, into waves of half-period, of quarter-period, and so forth. The first of these waves, corresponding to the "octave" above our main oscillation, is in the case of our temperature phenomenon a six-monthly fluctuation. It is a very curious phenomenon, whose cause is not yet well understood, and of it we shall have but little to say in the present paper.

When we have defined, in regard to the main temperature wave, the mean-value and the half-range, we get, by addition or subtraction of this latter value from the former, to what we may call the Mean Maximum and the Mean Minimum temperatures. They are not strictly the mean maxima or mean minima of the year, for to determine these we should have to take into our calculations the influence of the half-yearly and other higher oscillations of temperature. But as a rule even the half-yearly fluctuation is of no great magnitude, and the higher oscillations are very small indeed, so small that we can scarcely say whether they are real phenomena or (as is much more probable) are mere appearances due to our imperfect data. In any case, the approximate Mean Maxima and Minima, as we have defined them,—the maxima and minima, that is to say, of the fundamental sine-wave,—are features of considerable interest, whose local variations are often well worth studying.

Let us now begin, after this short introduction, to consider the main results of our temperature investigations.

Our object is to understand the temperature phenomena of the North Sea, and of the waters which surround the other coasts of our own islands. But all our coastal waters are but a part of the great system of waters of the Atlantic Ocean, and we cannot properly understand any of our local phenomena without some preliminary knowledge of the ocean temperatures of the whole North Atlantic basin.

The temperature phenomena of the ocean are closely interconnected with the system of ocean currents; and these in turn are correlated with the system of prevailing winds, and are greatly affected by the form itself of the ocean-basin.

Were the whole globe covered by a shoreless ocean, the distribution of temperature therein would be comparatively simple; and in the absence of wind it would be very simple indeed. For the main phenomenon would be that of a steady cooling of the surface of the sea from the Equator towards the poles, the temperature varying from a maximum at the one to a minimum at the other, as a simple function of the cosine of the latitude. At the same time, the waters of the ocean would not be stationary; for the waters cooled in the neighbourhood of the pole would be rendered heavier thereby, and would tend to sink, while the warmer and lighter waters farther south would always tend to float over the colder and heavier layers. There would, in short, be a steady drift to the northward of warm surface waters from the Equator, while the cold waters of the pole would form a steady return-current at the bottom. The obvious effect as regards the surface temperatures would be that at any point

north and south of the Equator the surface waters would be a little warmer than the stagnant waters of a shallow and currentless ocean. The same phenomenon occurs at present, with certain modifications.

At the same time, also, the whole mass of water would tend to follow a curious spiral course, in consequence of the rotation of the earth. For as the earth rotates, every particle at its surface is travelling through space from west to east, with a velocity which is greatest at the Equator, and falls to nothing at the pole; and so long as a water particle has no other motion impressed upon it, it shares, by virtue of its inertia, in this rotatory motion of the earth's surface, and does not change its place relatively to the solid earth below. But let us suppose that our water particle begins to move from the Equator northward, under the influence of the convection current described in the last paragraph; then it embodies two velocities, (1) its own proper velocity northward, and (2) that velocity in an eastward direction which it had acquired at the Equator from the rotation of the earth. As it proceeds northward, it comes to a part of the earth's surface which is travelling eastward with a less velocity than its own—a less velocity, that is to say, than the normal Equatorial one; and the obvious consequence is that the particle will have a component of velocity eastwards greater than that of the solid ground over which it has come to lie, and will, in short, be found travelling, relatively to the earth's surface, eastward as well as northward. The moving particles, whether they be going northward or southward, will always tend to swerve to the *right* in the northern, and to the *left* in the southern hemisphere. There will, that is to say, be a constant tendency for the whole surface waters of the ocean, as they move poleward, to swirl in a north-easterly drift in the northern hemisphere, and in a south-easterly drift in the southern. And the cold currents from the pole, travelling in the opposite direction (whether at the surface or the bottom), will, in contrary fashion, be swayed towards the west as they travel towards the Equator. But under the conditions which we have imagined of an uninterrupted ocean, the conditions would be symmetrical all round; and though the great drift would be sweeping on its spiral course, the temperature phenomena would soon settle down into equilibrium, and no temperature fluctuations would be apparent, save for the steady fall from the equatorial to the polar regions.

But the case is very different within the definite boundaries of an actual ocean. Here the currents are on the one hand confined to the bed of a channel, which in the case of the Atlantic is like that of a vast and winding river; on the other hand, they eddy here and there in great pools, such as the North Sea and the much greater basin of the Caribbean Sea; and they stream or rush through gateways, such as Davis Straits or the English Channel, or the broader lanes to east and west of Iceland.

Moreover, while it was customary at one time to attribute the main systems of ocean currents almost entirely to the two phenomena which we have just described, namely, to the convection currents set up by equatorial heat and polar cold, and to the side-way motion impressed upon them by the rotation of the earth, nowadays it is clearly understood that the direct action of the winds is also a factor of very great and even of more manifest importance. But this

is not the place to attempt a further discussion of the cause or origin of the ocean currents. The subject is of great complexity, and there are many points on which hydrographers are not yet agreed. Let us simply try to set forth, in a few words, the outline of the North Atlantic current-system, so far as it is necessary to bear it in mind in our consideration of the temperature phenomena (Fig. 1B).

On either side of the Equator there runs, in a westerly direction, a great equatorial current, which is, in the main, due to the steady, long-continued influence of the trade-winds. Guided by the northern coast of the South American continent, from Cape St. Roque north-

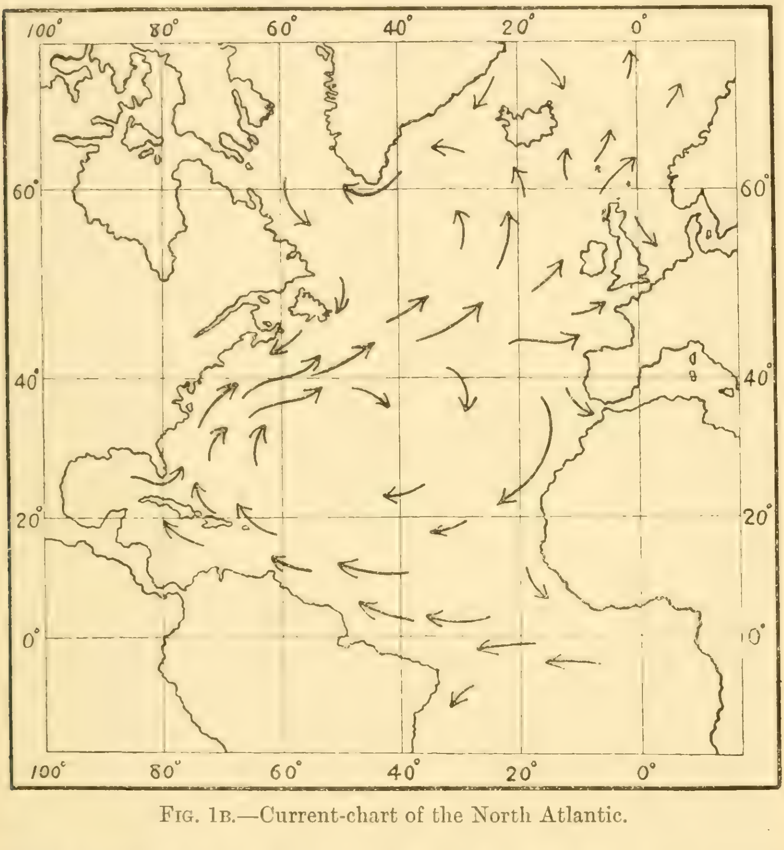


FIG. 1B.—Current-chart of the North Atlantic.

ward, a great part of this current, from both sides of the Equator, is carried into the Caribbean Sea and the Gulf of Mexico; while a comparatively small part, splitting off at Cape St. Roque, is deflected southward along the coast of Brazil. The water so heaped up in the West Indian seas must find its outlet; for, in any body of water, however small or large, you cannot disturb or alter the level of any part without affecting the whole. Partly, then, through a storage of energy produced by the heaping up of this body of water, partly through its own lightness caused by the intense heating to which it has been subject in the landlocked West Indian seas, a great current issues round Cape Sable, and skirts the coast of Florida and

the eastern shores of the United States; it is that "great river in the ocean," which is called the Gulf Stream. This narrow river-like Gulf Stream gradually loses its heat, its speed, and its river-like form, and at the same time it is deflected westward, partly by the direction of the American coast, partly by the influence of the earth's rotation upon its northward velocity. It is presently caught up by the strong westerly winds which are characteristic of the north temperate Atlantic, and by all these influences combined (and especially the last), it is merged in that great east-going drift which is still often called the "Gulf Stream," but which it were better to call the North Atlantic Current. It is this great easterly current which warms our own western shores, ameliorates the climate of the whole coast of Norway, tempers that of distant Spitzbergen, and sends its offshoots not only into the North Sea, but also to both sides of Iceland, to the east coast of Greenland, and even dips round Cape Farewell into Davis Straits. On the other hand, another portion of the same great Atlantic drift eddies southwards, by Spain and the Moroccan coast, by the Cape Verdes towards the Equator, to resume its circuit westward in the Equatorial Current.

Within this vast swirl of waters, between the westerly drift of the Equatorial Current to the southward, and the easterly drift of the "Gulf Stream" or Atlantic Current far to the north, lie the almost motionless waters of the Sargasso Sea.

The cold currents from the pole run southward, in great part, as we have already said, below the surface, and even at the bottom of the ocean; this being due to the greater density of their cold waters, which are compelled to sink beneath the warm. But at the same time, much of the very cold water from the far north is largely mixed with fresh water from the Arctic ice and snow; and this admixture of fresh water may render the mixture lighter, in spite of its coldness, than the warm but salt waters of the ocean. Accordingly, we have not only the cold returning bottom currents to think of, but we have also certain cold, south-going surface currents, and the greatest of these is that which coasts down the east side of Greenland, close to the shore, joins with a still larger bulk of water from Davis Straits and Baffin's Bay, and again with more cool water from Newfoundland and Labrador, and then (deflected *westward* by the rotation of the earth) hugs the coast of the United States, between the Gulf Stream and the shore.

We are now at length in a position to consider the Mean Surface Temperatures of the North Atlantic, and to understand them in relation to the system of currents which we have so briefly described.

On the southern border of our chart (Fig. 1), where it commences in about lat. 30° N., we see that the mean annual temperature is about 22° C., but that, as we pass westward from the African coast towards Florida, the temperature gradually increases from about 20° to somewhat over 23°. This gradual increase is the direct result of the great North Equatorial Current; for, evidently, at the eastern end of our line, we have cooler waters which have come down in the great eddy from the north (constituting the so-called Canary Current); on the western side, between about 50° and 70° W., we have the almost motionless waters of the Sargasso Sea, heated by

long exposure to a semi-tropical sun; to the westward of the Sargasso Sea, we have the hot north-going waters of the Antillean Current, and finally, still nearer to the shore, the still hotter waters of the Gulf Stream. For these latter phenomena, to the westward, our own temperature data are very scanty, and the isotherms on the map (westward of 70°) are filled in approximately from Dr. Schott's chart and other sources.

The next important feature in the map, and the most striking of all, is the band of close-packed isotherms running from about Cape Hatteras, more or less parallel with the American coast, until it bends more to the northward beyond Newfoundland; here the close-packed isotherms begin to spread apart, opening out like a fan, to cover the whole region of the North Atlantic. This band of isotherms, or region of rapid change of temperature, is evidently the simple and natural result of the meeting of the warm waters of the Atlantic with the cold waters brought down from the north by the Labrador Current. The latter first drives a wedge into the warm ocean to the east and south-east of Newfoundland; and here, where the hot and cold waters lie side by side, fog and rain and snow, according to season, are the inevitable consequence. And all down the American coast, as far at least as Cape Hatteras, the cold current hugging the shore (under the influence of the earth's rotation), and the hot current passing northward on its outer side, produce within a narrow belt a succession of rapidly changing temperatures, which appear on our chart as the band of close-packed isotherms.

To the northward and eastward, in the middle and eastern Atlantic, we see that the isotherms are all more and more curved or bowed, with their convexities to the north, or rather to the north-east; and accordingly, along a line from Labrador towards the Irish coast, we are passing steadily from colder to warmer waters. Along this line, beginning at the west, we start from the cold Arctic waters which have come down Davis Straits and out of Baffin's Bay; and the warmer waters which we gradually reach are those which have come from the southward, out of the great Equatorial Current, partly by way of the wind-swept North Atlantic Current of which we have spoken, and partly as a consequence of the general tendency of the warm and light ocean water to creep northwards, slewed as it is, at the same time, eastward by the rotation of the earth.

Off our own shores we see the Atlantic Current, or so-called "Gulf Stream," carrying part of its warm waters into the narrow seas, that is to say, into the Irish Sea, and through the English Channel into the North Sea. Bends in the isotherms correspond visibly with this phenomenon: while the curved isotherms of the ocean become still more curved to the northward of our islands, as the great current passes on its way to the coasts of Norway and far into the Arctic Sea. Eastward of Iceland these isotherms show a subordinate bend in a southerly direction; this is an indication (which more detailed information would probably make much more distinct) of a branch of the great cold water current coming southward from the pole: and indeed there is a series of gentle bends in all the isotherms to the north of Scotland (with their concavities to the north), indicating a slow southward drift of colder waters.

Returning to the western coasts of the British Islands, and pass-

ing from the south-west of Ireland southwards along the Spanish and African coasts, we see the isotherms all gently bending to the southward. The water near to, and for some distance from, the continental coast is cooler than at corresponding latitudes in mid-ocean: this being the simple consequence of that southward set of the great eddy, which here, on the eastern side of the ocean, draws down waters from the northward to take the place, and to follow in the track, of those which had been carried westward by the great Equatorial Current. In short, it is possible throughout to interpret this Temperature Chart of ours in terms of the *current-system* which controls the motions of all the waters of the Atlantic.

In Fig. 2 we have another chart, which shows, this time, the annual range, or total rise and fall between winter and summer, of the Atlantic temperatures. For an important part of the ocean, especially to the north-west, in the Greenland Seas and in Davis Straits, we have all too little information for the construction of such a map; but we can see, more or less, how the lines are bound to run. In Dr. Schott's *Geographie des Atlantischen Oceans,* the reader will find a similar map (on a smaller scale), which agrees in the main, but differs in part, from the general picture which I have given of the phenomena.

Looking at this chart as a whole, we at once see that it is in the open ocean (as we might expect) that there is least seasonal change of temperature. The great mass of ocean water acquires and loses heat slowly, while in the shallower waters, and in the neighbourhood of land, the seasons show a much more marked effect. In mid-ocean, from the southern border of our map to the neighbourhood of Iceland, the seasonal fluctuation only varies between about 4° and 7° C. Doubtless it is much greater close to the Icelandic coast, but on this point we have at present no definite information.

In the British area the variations in temperature-range are very simple and diagrammatic. A short distance from our western and northern coasts we have everywhere the typical oceanic condition of a small seasonal fluctuation, somewhere about 6° C., but as we pass into the narrow seas the range rapidly increases. Off the west of Scotland and in the Irish sea the increase of range is not great, for there is free and open contact with the ocean. But as we pass up the English Channel the range steadily increases; and within the North Sea, as we pass from the Shetland region to the German Bight, we see the annual range gradually increasing from about 6° to at least 14° C.

On the other side of the ocean, from Newfoundland to the American coast, we have a still more marked increase of seasonal range. In the neighbourhood of the peninsula of Gaspé our chart shows a range of about 16° C., but it may well be greater in these shallower waters, to which our sources of information do not extend. The steady increase of temperature-range in this part of the ocean, just where in our former map we saw the close-packed isotherms of mean temperature, is doubtless connected with a tendency for the two opposing currents, cold and hot, to vary in magnitude or force with the seasons of the year, and more or less to shift their relative positions accordingly. In short, we are probably here observing a somewhat mixed phenomenon, consisting in part of a

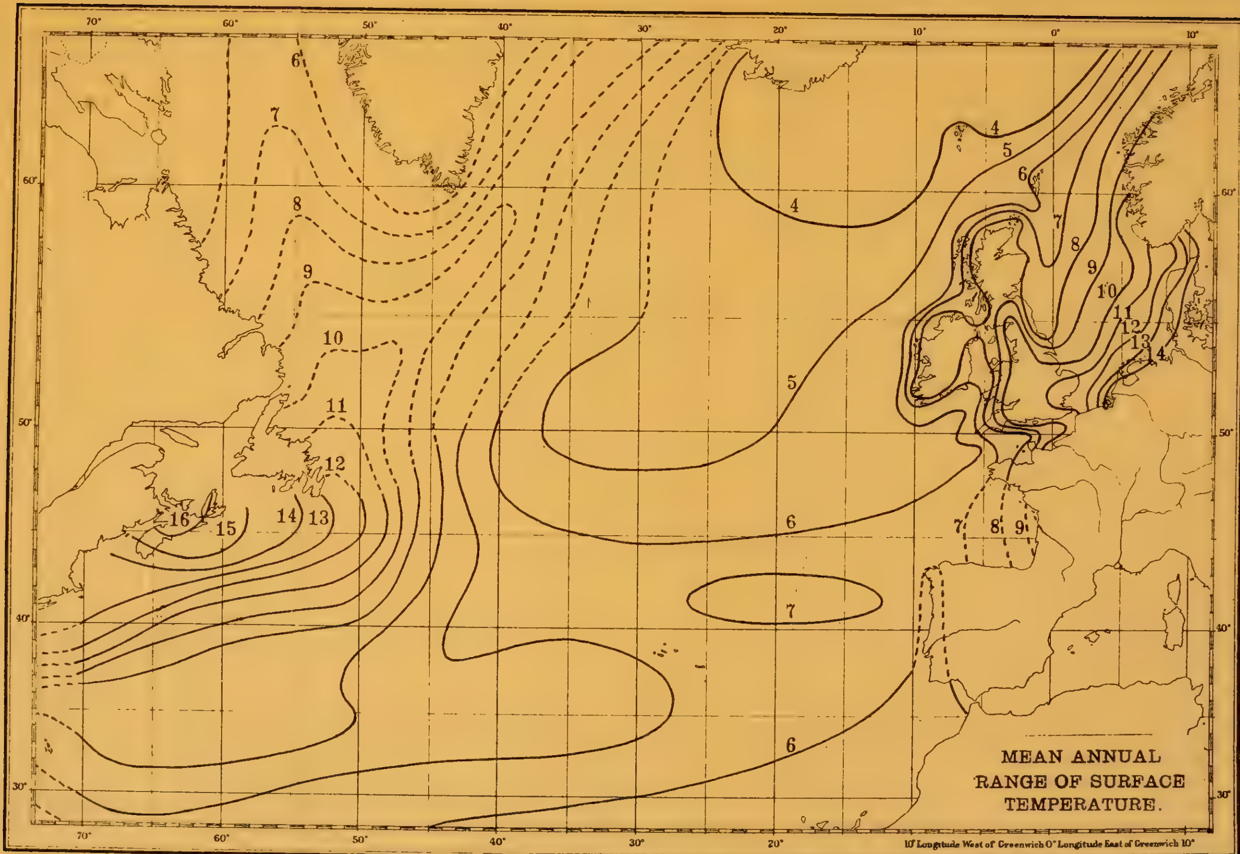

MEAN ANNUAL
RANGE OF SURFACE
TEMPERATURE.
10° Longitude West of Greenwich 0° Longitude East of Greenwich 10°
70°
60°
50°
40°
30°
20°
10°
0°
60°
50°
40°
30°
4
5
6
7
8
9
10
11
12
13
14
15
16

FIG. 2.

true seasonal fluctuation of temperature, and in part of a tendency for the actual body of water present in a given place to change places with another, characterised by very different temperature phenomena.

Some minor features in this map are not very easy to explain. For instance, there is good evidence that in a large patch of water lying between Spain and the Canaries, the range of temperature is a full degree centigrade greater than that of the waters which surround it; but the cause of these increased amplitudes is not obvious.

It will be seen that the lowest range represented anywhere upon our map is 4° C., which is shown as occurring in a large mass of water southward of Iceland, and extending north of Faeroe into the Norwegian Sea. Our data for this region are somewhat scanty, and it is probable that the actual phenomena are much more complicated than as they are represented in our chart. In Dr. Schott's map, a large patch of water is shown in the Atlantic, between Britain and Labrador, with a mean annual range of 5° C. and less, as in our own chart; but on the other hand Dr. Schott represents much larger instead of smaller amplitudes north of this region, between it and Iceland. He shows, in fact, the isotherms of large amplitude, characteristic of the Newfoundland and Davis Straits region, bending up not only to the westward, but also to the south and south-east of Iceland. After a careful and repeated study of the harmonics which we have derived from the data given in the Danish Year-Book, I feel confident that the distribution shown in our chart (so far as the Danish data extend) is more nearly correct than is Dr. Schott's.

We may be sure that there is a region characterised by very small amplitudes in the cold current flowing down the East Greenland coast, and also in the cold waters of Davis Straits, especially on its western side. For, for two different reasons, an exceptionally small amplitude is characteristic both of the very hot and of the very cold regions of the ocean. At the Equator, the amplitude is small, for the simple reason that the seasonal change of air-temperature or of solar radiation is also small; as a matter of fact, in the Equatorial Atlantic, the range of temperature is not more than 2°, and is said to be, over a considerable area, less than 1° C. In the polar waters, on the other hand, there is a small annual range of surface temperature, in spite of the fact that the seasonal changes are very marked indeed; and the obvious reason is that the water is already ice-cold, or nearly so, and is for the most part intermixed with ice. Below its mean temperature it cannot fall much, or it would freeze; above its mean temperature it has not time to rise far, for the influx of summer heat is mainly employed in melting the floating ice.

We have now dealt, briefly, with the temperature phenomena of the North Atlantic, in regard (1) to the mean temperature of the year, and (2) to the mean range or amplitude of the annual seasonal fluctuation. It remains to consider the *phase* of this sine-wave, from which we derive the corresponding dates of minimal or maximal temperature. But the phase-angle is not so easy to determine with the requisite accuracy as the other co-efficients of the sine-function.

For the phase-angles are all near together, corresponding to dates of minimal temperature (calculated from the first sine-wave) which vary no more than from about the middle of February to before the middle of March, or an angular difference of less than 30° out of 360°; and in charting our results, to show the differences of phase from one part to another of the map, we should at least like to group together phases differing from one another by not more than 5°, or five consecutive days in the year. Now it is soon found that, in analysing such series of numbers as we have here to deal with, each series consisting of only twelve (monthly) data, and all the numbers being in the form of more or less rough approximations, we cannot always count on so much accuracy as 5° in the determination of the phase-angle: our results, from one station to another, are apt to be much less concordant, and to form less smooth and even series, than is the case with our determinations of mean temperature and of mean amplitude. Nevertheless it appears quite possible to give a rough and preliminary chart (Fig. 3) showing the main features of the variations of phase over the North Atlantic area; although it must be remembered that this result has been arrived at by a much more liberal process of "smoothing" of the individual values than we have applied, or had any occasion to apply, to the results for mean temperature and amplitude.

According to our chart, such as it is, there are three regions represented where the phase is most retarded, where, that is to say, the epochs of minimal, or of maximal, temperature fall latest in the year. These three regions are (1) off the African coast, near the Cape Verdes, where the minimum appears to come somewhere about the middle of March; (2) close around Newfoundland, where it comes in the first week of March; and (3) off the North of Scotland, where it arrives in the last week of February. There are, correspondingly, three regions of acceleration, in all of which the date of minimum temperature falls at, or even a little before, the middle of February. These are (1) off the eastern coast of the United States, in the region round Cape Hatteras; (2) in the northern Atlantic, to the south of Iceland: and (3) in the east and south-east of the North Sea.

Let us now, before proceeding to our twelve monthly charts of the temperatures of the North Sea and the neighbouring waters, look a little more closely at the charts which represent, for these waters, the mean phenomena which we have been discussing for the general surface of the ocean.

In Fig. 4 we have a chart of the Mean Annual Temperature of our British Coasts and the adjacent seas. We see again the main features which we have spoken of in connection with the eastern Atlantic, that is to say, the inflections which follow the course of the so-called "Gulf Stream" or North Atlantic Current, and also of that comparatively small body of cold water which comes down by the east coast of Iceland. But besides the direct influence of these currents, we now perceive that there is a strong tendency for the mean temperature to be lowered in the neighbourhood of land, as compared with the temperature of the open ocean. All the isotherms bend strongly to the southward as we approach the Scottish, the

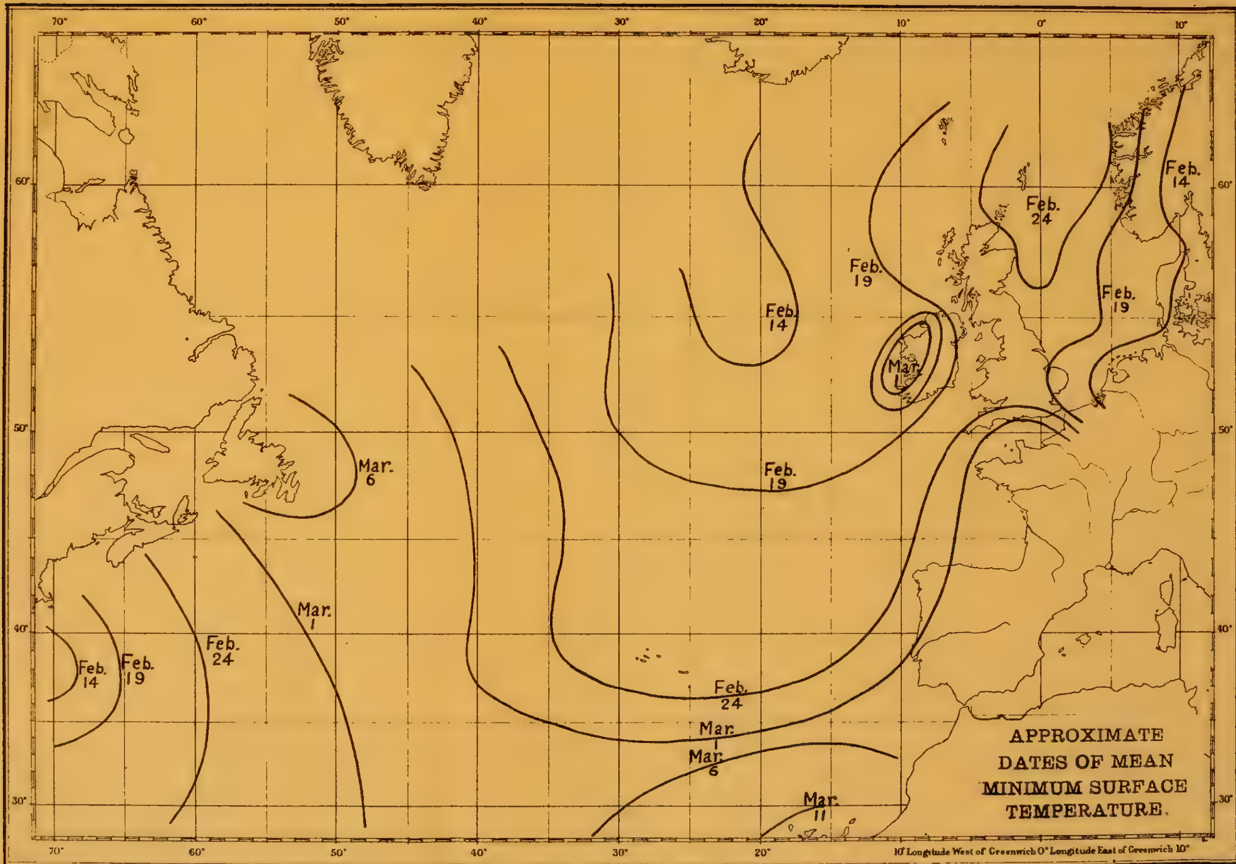
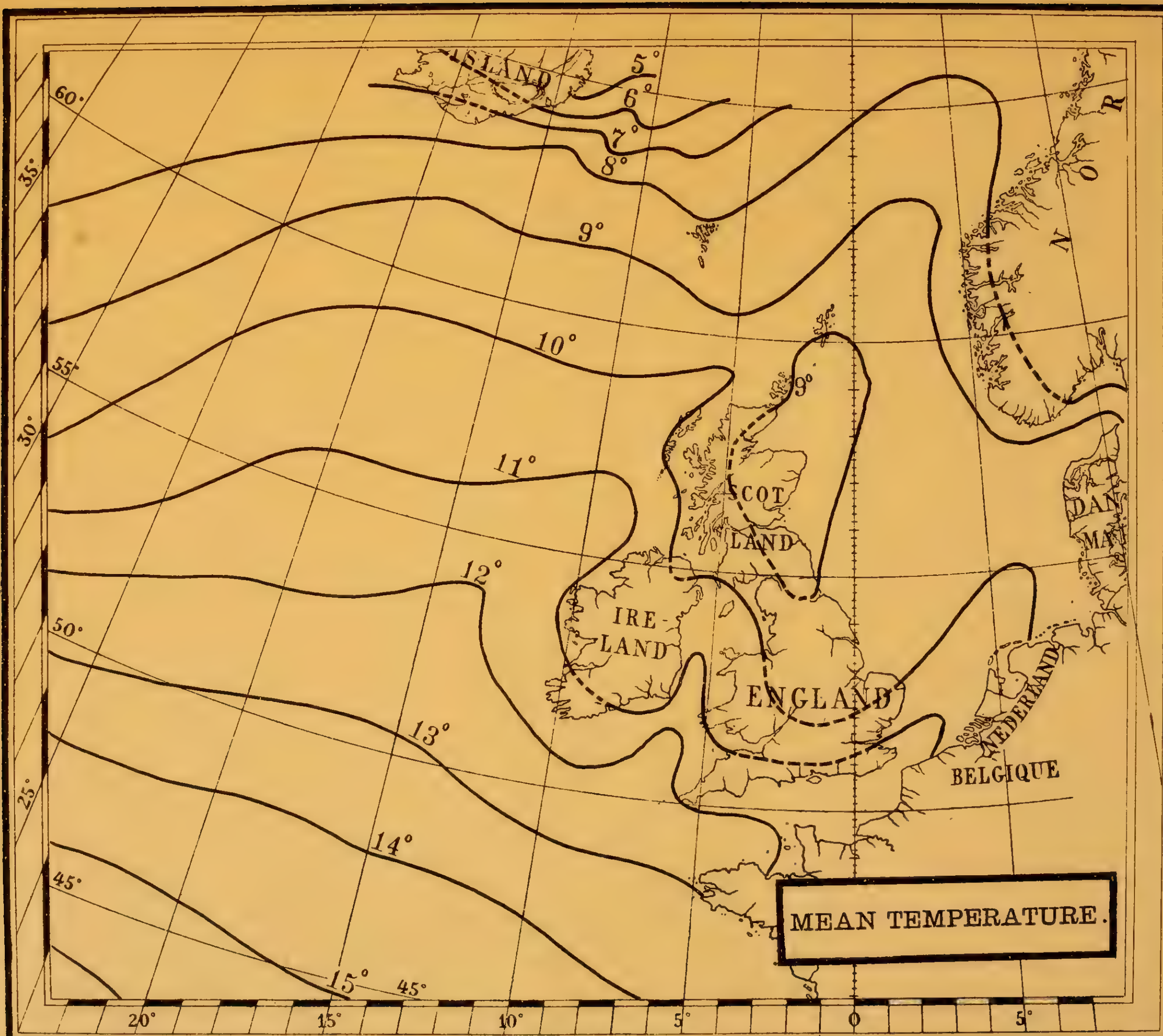

APPROXIMATE DATES OF MEAN MINIMUM SURFACE TEMPERATURE.
70°
60°
50°
40°
30°
20°
10°
0°
10°
60°
50°
40°
30°
Feb. 14
Feb. 19
Feb. 24
Mar. 1
Mar. 6
Mar. 11
10° Longitude West of Greenwich 0° Longitude East of Greenwich 10°

FIG. 8.



ISLAND
5°
6°
7°
8°
9°
10°
11°
12°
13°
14°
15°
9°
SCOT
LAND
IRE-
LAND
ENGLAND
NEDERLAND
BELGIQUE
DAN
MA
N
O
R
MEAN TEMPERATURE.
60°
55°
50°
45°
45°
35°
30°
25°
20°
15°
10°
5°
0
5°

FIG. 4.

Irish, and still more noticeably, the Norwegian coasts; and this strong inflection of the isotherms is more than can be accounted for by the convection of heat due to direct current-action. On the other hand, the isotherms farther to the south, as they approach the coast of France, are but slightly deflected. All this is part of a phenomenon which was diligently studied about the middle of last century by various meteorologists, and especially by Professor Dove of Berlin, and Professor James Forbes of Edinburgh.*

As these investigators showed, the effect of land in modifying climatic temperature conditions is twofold. In the first place, the effect of a neighbouring land-mass or continent is to exaggerate the Variation of Temperature which is due to the seasons: the temperature of the ocean is always steadier, or more nearly constant, than that of the land or that of the inshore waters. Secondly, the Mean Annual Temperature is also affected by the presence or neighbourhood of land; and this influence is also in the way of exaggeration, a northern latitude being all the colder, and a tropical latitude all the hotter, on or in the neighbourhood of land. It follows from this that there is an intermediate zone where the presence of land makes no apparent difference, and this, in the northern hemisphere, would seem to be somewhere about 45° N. lat. As Professor James Forbes pointed out, the accumulation of land in tropical Africa produces a temperature in excess of the mean temperature of the earth's surface at a corresponding parallel of latitude, while in Siberia the effect of the great concentration of land is precisely the reverse, the temperature there being considerably below the mean of the parallel. In short, every place upon the earth's surface has a mean temperature of its own, which we may look upon as compounded of two parts—(1) that which depends upon latitude alone, and (2) that which depends on the distribution, and the relative areas, of land and water. This latter factor is an exceedingly complicated one, and it is not necessary for our purpose to analyse it in detail. Its influence is in part direct, depending on the very different "thermal capacities" of land and of water, whereby a given quantity of solar heat produces a much greater change of temperature on land than on water; while the indirect effects are both numerous and important, and are chiefly seen in the wind-currents as they in turn are affected by the unequal heating of the land and water areas, and in the sea currents, as these are profoundly modified by the topographical features of the coast-line.

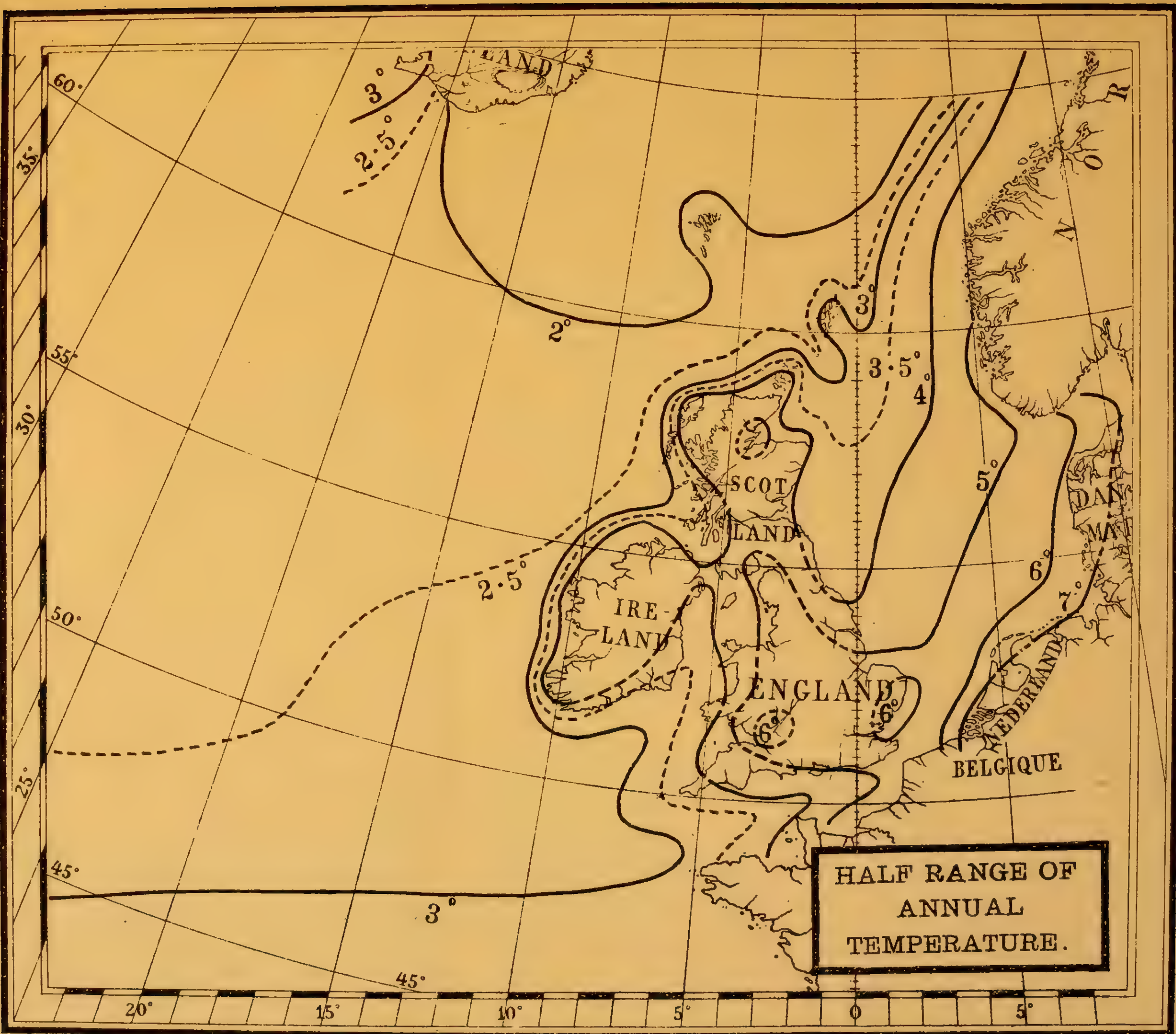
But since it is not our business to attempt to analyse the nature of these and other similar phenomena, let us merely attempt to examine the general effect of the presence of land, and of its particular topographical characters, upon the sea temperatures of our area; and this we may do by taking as a standard of comparison the temperature features along some line in the Atlantic, sufficiently far from shore, and by then representing our own North Sea and other coastal temperatures, not as they actually are, but in the form of differences from the oceanic standard of comparison. This is the method (already alluded to) which was introduced about the middle of last century by Dove, and which he called the study of "thermal anomalies."

* "Inquiries about Terrestrial Temperature," *Trans. R.S.E.*, xxii. pp. 75–100 (1859), 1861.

In Fig. 5, we have a representation of the mean thermal "isanomalies" of our seas, as compared with the mean annual temperatures along the meridian of 15° W. And here we encounter a certain inevitable difficulty, from the fact that neither this nor any other meridian in the North Atlantic can serve us throughout as a true standard of oceanic conditions, unaffected by currents or by the

Fig. 5.—Isanomalies, compared with the mean Annual Temperature of 15° W., in corresponding latitudes.

direct influence of the proximity of land. In the case of the meridian of 15° W., we find that, until we approach Iceland, the mean temperature falls in a smooth curve, very nearly in direct proportion to the cosine of the latitude; but in the neighbourhood of Iceland we have a somewhat sudden and rapid fall. In short, our standard of comparison becomes itself anomalous in the neighbourhood of 65° N. lat.; and accordingly our thermal anomaly in the North Sea and



HALF RANGE OF ANNUAL TEMPERATURE.

FIG.6.

Norwegian Sea, as compared with the conditions along the meridian of 15° W., will, in the same high latitude, be considerably perturbed by this anomalous condition of the standard of comparison. This is at once apparent in our chart. We see from the latter that the whole basin of the North Sea, and all the waters of the British coasts are notably cooler than the mid-Atlantic waters in corresponding latitudes, and the relative cooling is nowhere less than half a degree centigrade. In other words, an isanomaly of $-\cdot5°$ runs from the neighbourhood of Bergen round the west coasts of Scotland and Ireland, and is continued southward at some considerable distance from the French coast. It is followed at no great distance by an isanomaly of $-1°$ C., which line, however, visibly bends into the North Sea, the Irish Sea, and slightly into the mouth of the English Channel. In the greater part of the North Sea, the Skagerrack, the Irish Sea, and the English Channel, the anomaly lies between $-1°$ and $-2°$ C. Off the east coast of England and Scotland, the west coast of Denmark, and a considerable stretch of the southern and eastern North Sea, the anomaly runs from $-2°$ to $-3°$ C., and it exceeds $-3°$ C. in a small area in the German Bight, and again in the Cattegat. Doubtless as we approach and enter the Baltic, the anomaly will be found to increase greatly.

In the Norwegian Sea, between Shetland and Færoe on the one hand and the coast of Norway on the other, the anomaly is a positive one, the mean temperatures tending to be higher than those of the Atlantic along our standard meridian of 15° W. This phenomenon, over which we need not spend time, is in part due to the warm waters of the Gulf Stream Current, which actually give to this region (or part of it) a mean temperature above what is properly due to such latitudes; and in part is due (as we have already indicated) to the fact that in the corresponding part of our standard meridian, the waters are unduly cooled by the neighbourhood of the great Icelandic land-mass, and by the cold current which eddies round the east coast of Iceland from the north.

The range of temperature between maximum and minimum, that is to say, *the amplitude of the fundamental sine-curve*, varies in a very regular manner in our area, as has already been said. The amplitude is largest in the German Bight and Cattegat, where the total range is over 14°, the half range (which is represented in our chart, Fig. 6) being over 7°. From this region the values steadily diminish as we pass on the one hand towards Shetland and Faeroe and on the other towards the mouth of the English Channel. In all cases as we enter the narrow seas from the ocean (that is to say in the Channel, at the northern opening of the North Sea and off both the north and south of Ireland), we see the curves of equal amplitude sagging inwards; that is to say the low amplitudes characteristic of the open ocean tend to show their influence for some distance into the narrow seas.

This chart of amplitudes is so simple in itself that we do not gain very much by transforming it into a chart of isanomalies. However, I have made such a chart (Fig. 7), for the sake of uniformity with the others, to show as in the other cases how this phenomenon of amplitude differs throughout our area from the conditions which obtain along the meridian of 15° W. It will be seen that we get an ex-

tremely simple diagram, which may be sufficiently described by saying that the curves of equal amplitude tend on the whole to run parallel with the Continental coast, from the Norwegian coast southwards, and that all but the innermost (and highest) of them have been, as it were, thrust outwards towards the ocean where the British Islands jut out from the Continental land-mass.

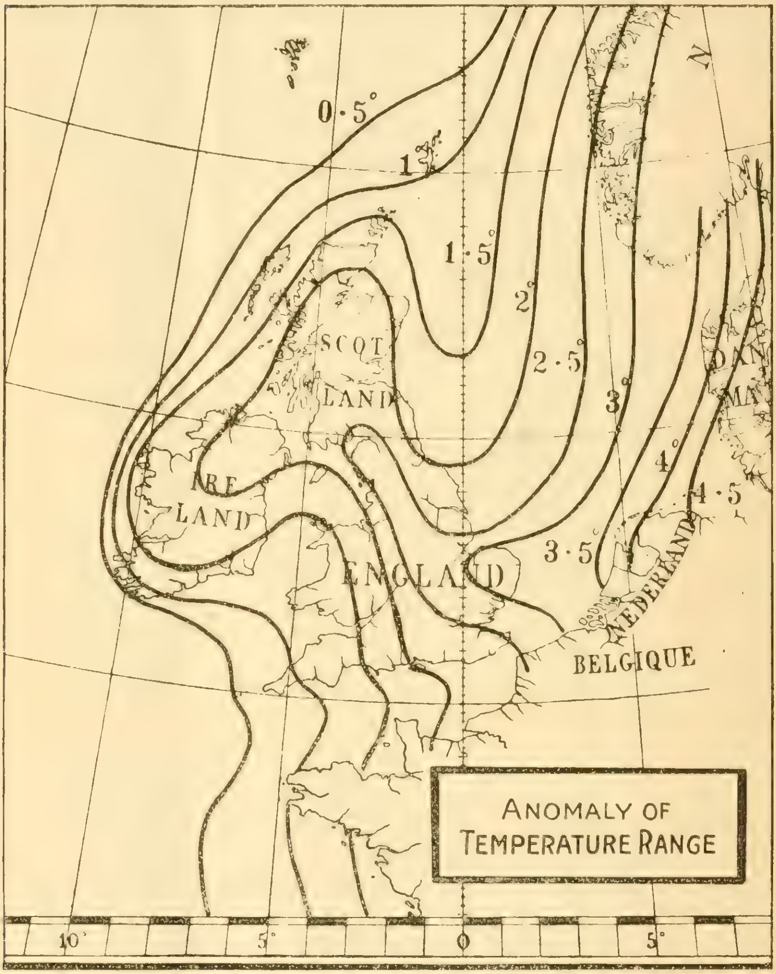
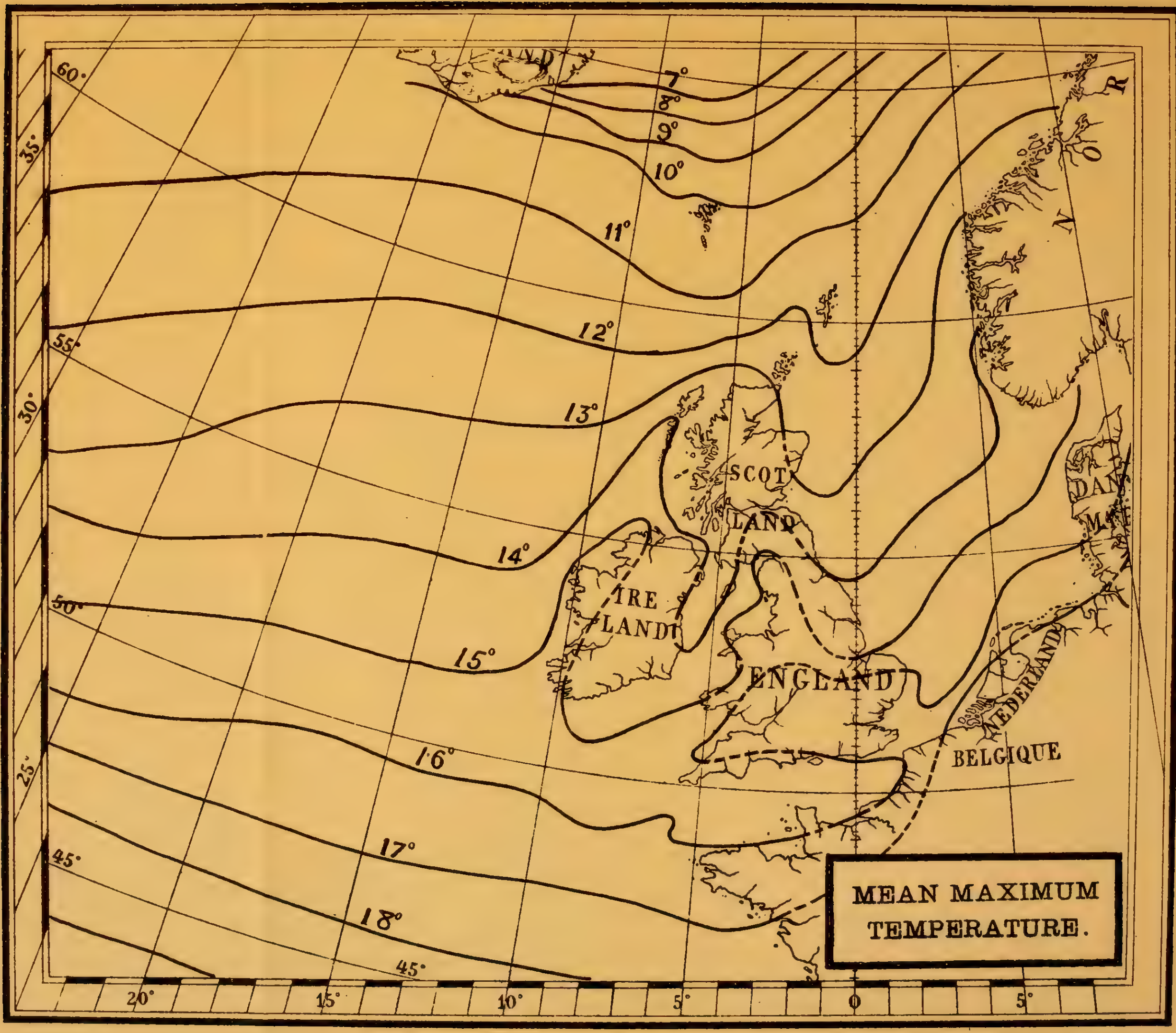


Fig. 7.—Isanomalies, compared as before with 15° W.

In Fig. 8 we represent the mean maximal temperature of the year, *as determined from the first sine-curve*; that is to say, the values represented are those of the mean temperature plus the half amplitude. The chart is a simple and regular one, and its chief features have already been referred to in connection with the corresponding chart of the North Atlantic. The contour-lines of equal maximal temperature, which run approximately east and west in the ocean, are bent strongly northward, firstly, along the west coasts of Great Britain and Ireland, and again still more markedly towards the Nor-


MEAN MAXIMUM
TEMPERATURE.
7°
8°
9°
10°
11°
12°
13°
14°
15°
16°
17°
18°
SCOT
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IRE
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ENGLAND
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FIG.8.

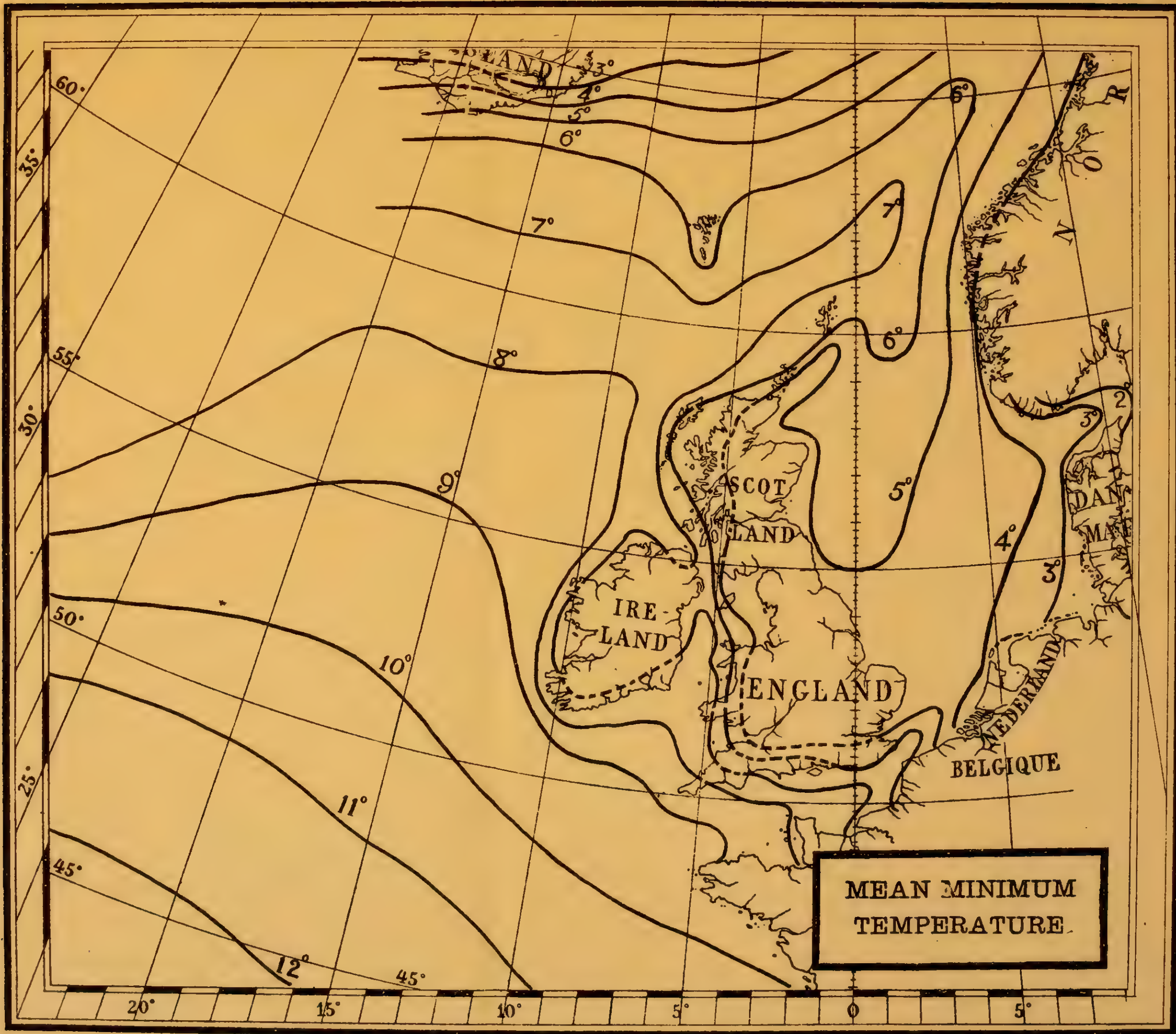

MEAN MINIMUM
TEMPERATURE
IRE LAND
SCOT LAND
ENGLAND
BELGIQUE
NEDERLAND
60°
55°
50°
45°
20°
15°
10°
5°
0
5°
3°
4°
5°
6°
7°
8°
9°
10°
11°
12°

FIG. 9.

wegian coast. The maximal temperatures off the North Cape are approximately the same as those off the south coast of Iceland, some 8° of latitude to the south, and the mean maxima in the German Bight are again similar to those which we find some 8° farther south in the open ocean.

In Fig. 9 we have a similar chart of the mean minimal temperatures: and here we have an almost precisely contrary distribution to

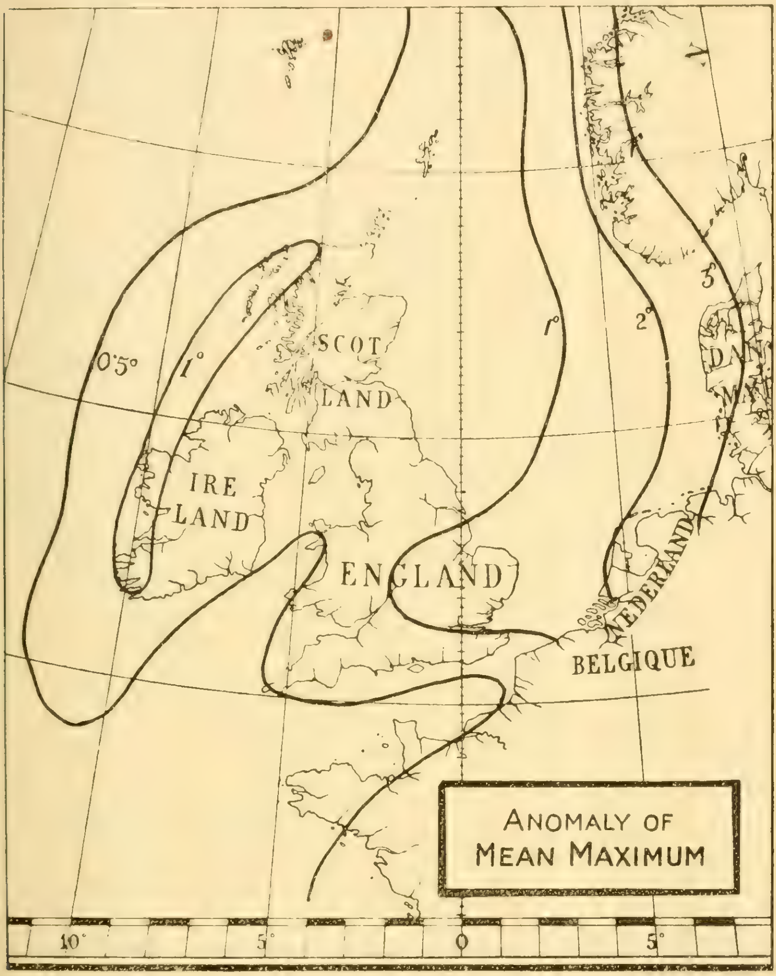


FIG. 10.

that of the preceding figure; that is to say, the oceanic isotherms are strongly bent to the southward, off our own west coast and the west coasts of the Continent. But together with this marked influence of the proximity of land in *lowering* the winter temperature of the sea, we also see very clearly the influence of the Great Atlantic, or "Gulf Stream," Current, whose warm waters proceeding on their north-easterly course towards the Norwegian coast constitute a region of relatively *high* minimal temperature; until we come still nearer to

the continental coast and find evidence, in the sharp southward bending of our isotherms, of the low winter temperatures which characterise the coastal waters.

Both of these latter charts, of mean maximal and mean minimal temperature, become considerably simplified when we translate them into charts of maximal and minimal anomaly.

In Fig. 10 we see the anomalies, as compared with 15° W., in

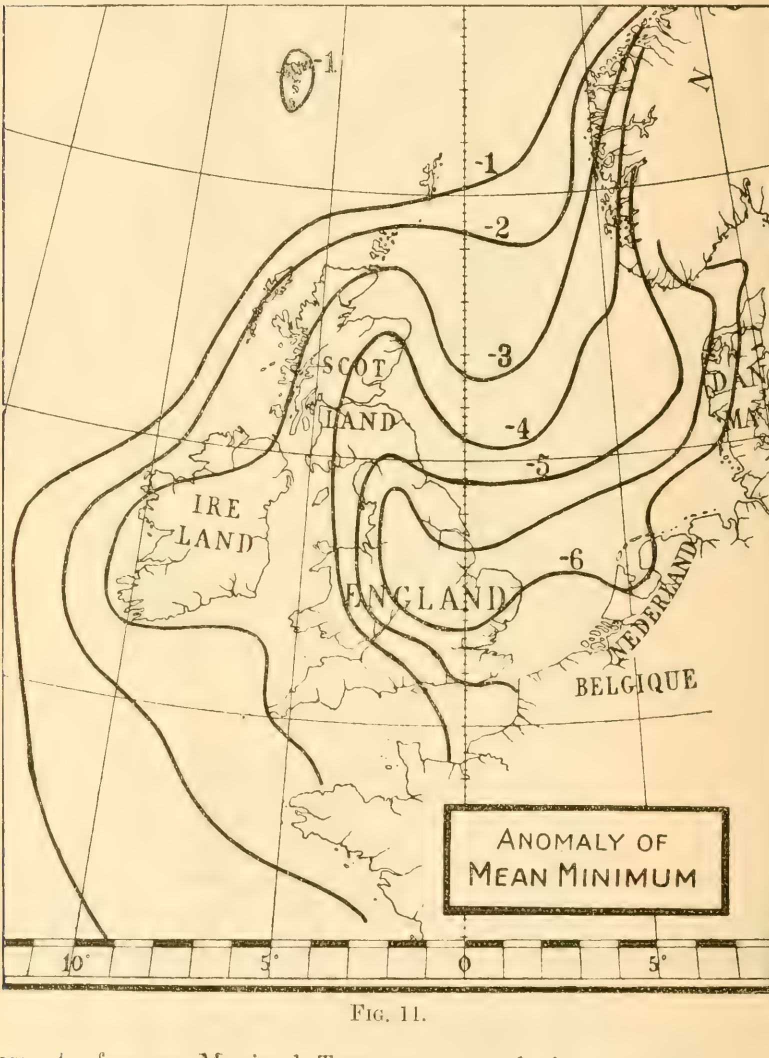


FIG. 11.

respect of mean Maximal Temperature, and these isanomalies, as will be at once seen, are of a simple and regular kind. Everywhere as we approach land, the maximal summer temperature (as calculated from the fundamental sine-curve) is higher than in the open ocean at corresponding latitudes, and everywhere the difference gets greater as we pass farther and farther into the narrow seas. In the English Channel and the southern portion of the Irish Sea, the mean

Maximum is less than half a degree higher than at 15° W. In the North Sea, the anomaly varies from less than 1° C. in the western half of the sea to over 2° C. along its eastern shores, and is above 3° in the German Bight and in the eastern part of the Skagerrack. Off the west of Scotland and west of Ireland, there is an area in which the anomaly is considerably higher than at the stations around; but the area so affected can only be roughly and approximately indicated on our chart.

As regards the mean Minimum Temperatures, our chart (Fig. 11), showing the anomalies from 15° W., has a different appearance from the corresponding chart of mean maxima. But it will be found that the difference is mainly one of degree, the proximity of land having a greater influence in lowering the winter temperatures than in raising the summer temperatures of the sea. While our maximal isanomalies never exceeded 3° C., our chart of minimal isanomalies shows a range of from 0° to 7° C. The general arrangement of the lines, however, is very much the same as before, and the largest anomalies are again found in the German Bight and as we pass through the Skagerrack towards the Baltic Sea.

When we come to examine our twelve monthly charts (Figs. 13–24) of Mean Sea Temperature we are struck by the very great differences which exist from one month to another in regard to the distribution and direction of the isotherms. These differences can all be understood, after due consideration, in the light of the general phenomena which we have now explained; and the chief cause of the altered direction of the isotherms, from season to season, evidently lies in the great *variation of amplitude* from one part of our area to another. About the month of June and again about the month of October the isotherms run approximately east and west across our area, subject of course to the various bendings or infoldings which are caused by currents and other secondary factors. But, on the other hand, from about February to April the isotherms around our coasts and especially in the eastern parts of the North Sea, run almost due north and south, while again from July to September they are steeply inclined in an opposite direction. This is all simply due to the fact that, at the season of minimum in early spring the waters in the south-eastern part of the North Sea are unduly cool, and the isotherms passing through this area are accordingly linked up with those far to the northward thereof. While, on the other hand, in summer and early autumn, about the season of the maximal sea temperature, the exceptionally heated waters of the eastern and south-eastern North Sea have a temperature similar to that of the ocean considerably to the southward.

It seems worth while, in order to get a general view of this phenomenon, to construct a series of schematic diagrams, such as those shown in Fig. 12. The construction of these diagrams is as follows: We begin by making a quadrilateral upon the chart, bounded on the east and west by the meridians of 5° E. and 15° W., and northward by the parallel of 60° N.; the south-western corner of our quadrilateral is in 50° N. and the south-eastern corner is in 53° N., that is to say in the southern North Sea, off the Frisian coast. Now suppose that we take, from month to month, the

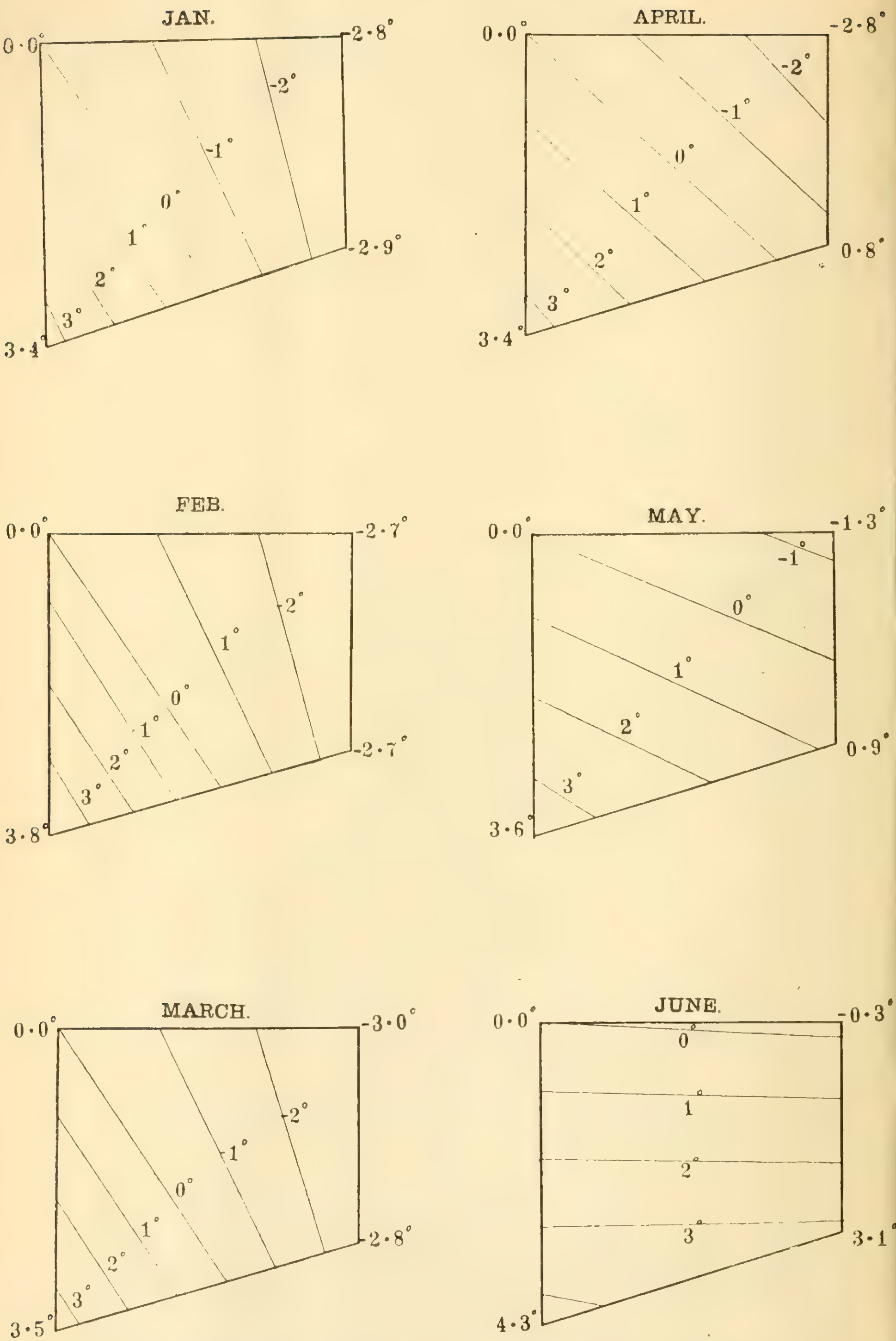


Fig. 12.—Diagrammatic surface-temperature gradients in an area bounded by 15° W. (60° N.–50° N.) and 5° E. (60° N.–53° N.).

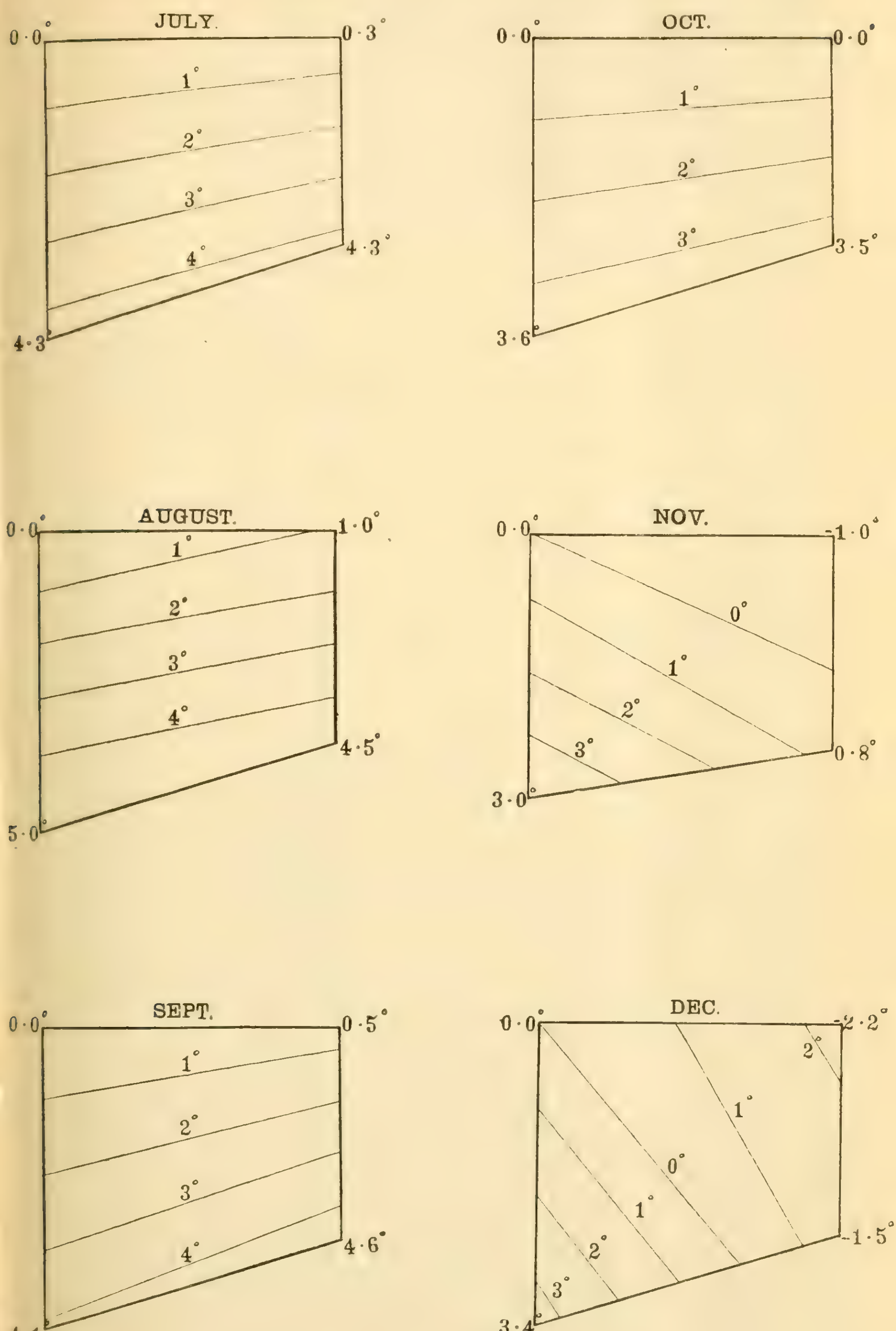


FIG. 12.—*continued.*

temperatures at the four corners of our quadrilateral, and attempt to draw a series of isotherms based on this information and nothing more. It is plain that we shall get a schematic representation which will correspond *approximately* to the actual facts, uncomplicated by the various bends and irregularities which are found around the various coasts. Look, for example, at our diagrammatic chart for March. The temperatures at the four corners of our quadrilateral, as found by interpolation from our Mean Temperature chart for that month, are as follows:

(60° N., 15° W.) 7·8° C.	4·8° C. (60° N., 5° E.)
(50° N., 15° W.) 11·3° C.	5·0° C. (53° N., 5° E.)

Let us now, in this and all the other cases, reduce the temperature in the north-western corner of our quadrilateral to nil; the corresponding temperatures will then be as follows:

·0° C.	–3·0° C.
3·5° C.	–2·8° C.

In other words, as we pass from the north-western to the north-eastern corner, there is a fall of 3° C.; from the north-western to the south-western corner, a rise of 3·5° C.; from the south-western to the south-eastern corner, a fall of 6·3° C.; and from the south-eastern to the north-eastern corner, a small or insignificant rise of 0·2° C. The mean gradient over the whole area of the quadrilateral is, accordingly, that which is shown in our diagram. In certain cases the gradient thus roughly arrived at tallies better than in other cases with that which we have before us in the full temperature chart; for instance in the month of February our chart is not at all good, owing to the fact that the northern boundary which we have chosen for it does not include the remarkable distribution of temperature in the neighbourhood of 65° N. which causes the isotherms in that region to make a sharp rectangular bend towards the south-east. But on the whole, and as a rough illustration, I think this series of diagrams is both useful and interesting, showing at a glance, as it does, the steady change in the direction of the temperature gradient from one season to another.

It is not necessary that I should describe in words the twelve monthly temperature charts which follow and to which the foregoing pages form a general introduction. Let me simply say again, as I said in the beginning of this paper, that these charts are published in the hope that they may serve a temporary purpose, and in the belief that they show a general approximation to the true conditions, such as all our work in particular areas may gradually correct and improve, until at length a series of mean values is arrived at which will be generally accepted as a standard.

In conclusion, I have drawn a series of isopleth diagrams, to illustrate (1) the whole annual periodic changes of surface temperature along various meridians, from 20° W. to 5° E., that is to say, from well out in the Atlantic to the eastern border of the North Sea; and (2) in two cases, namely, for 10° W. and for 0°, I have drawn similar diagrams showing the differences or isanomalies as compared with 15° W.

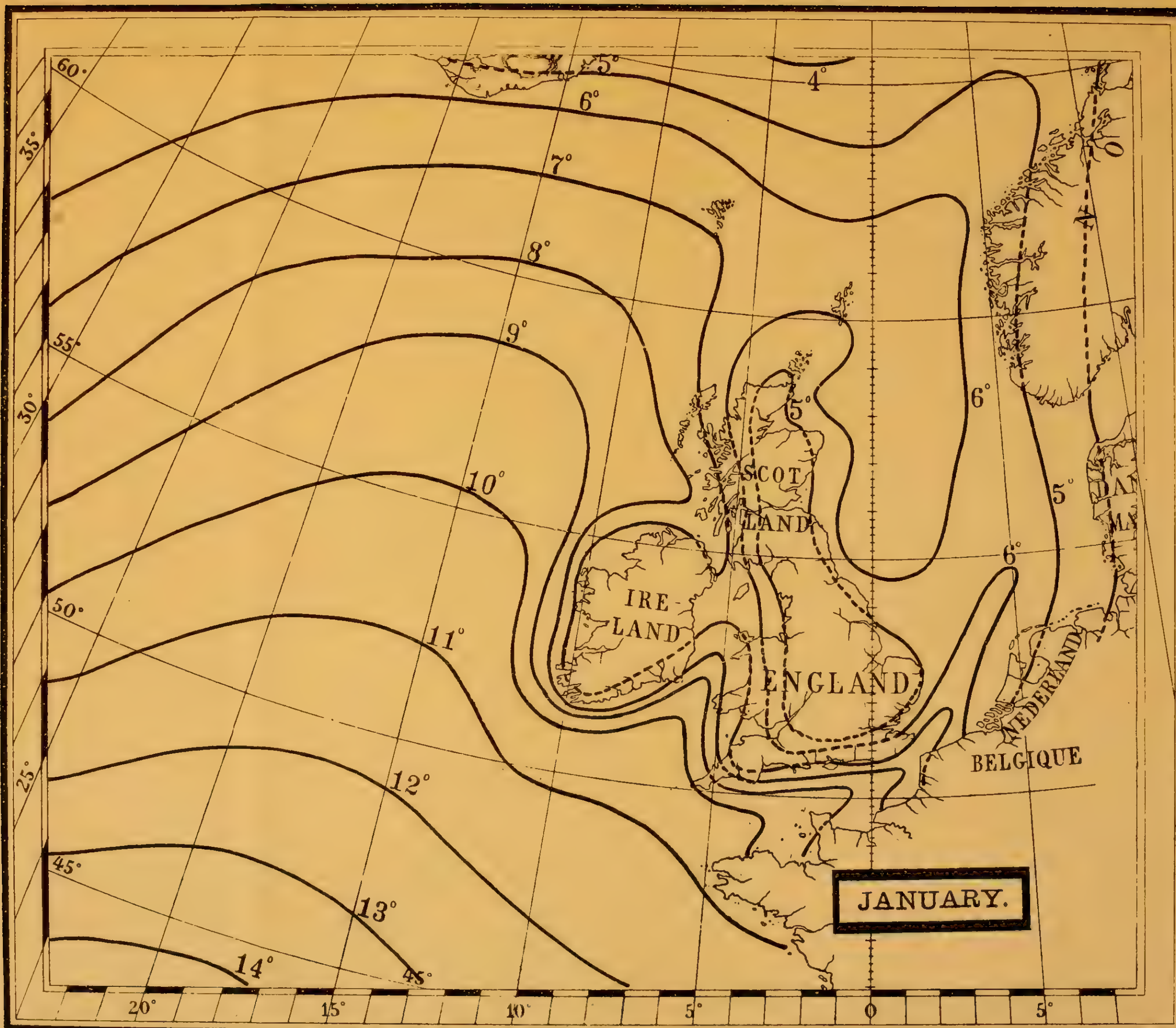
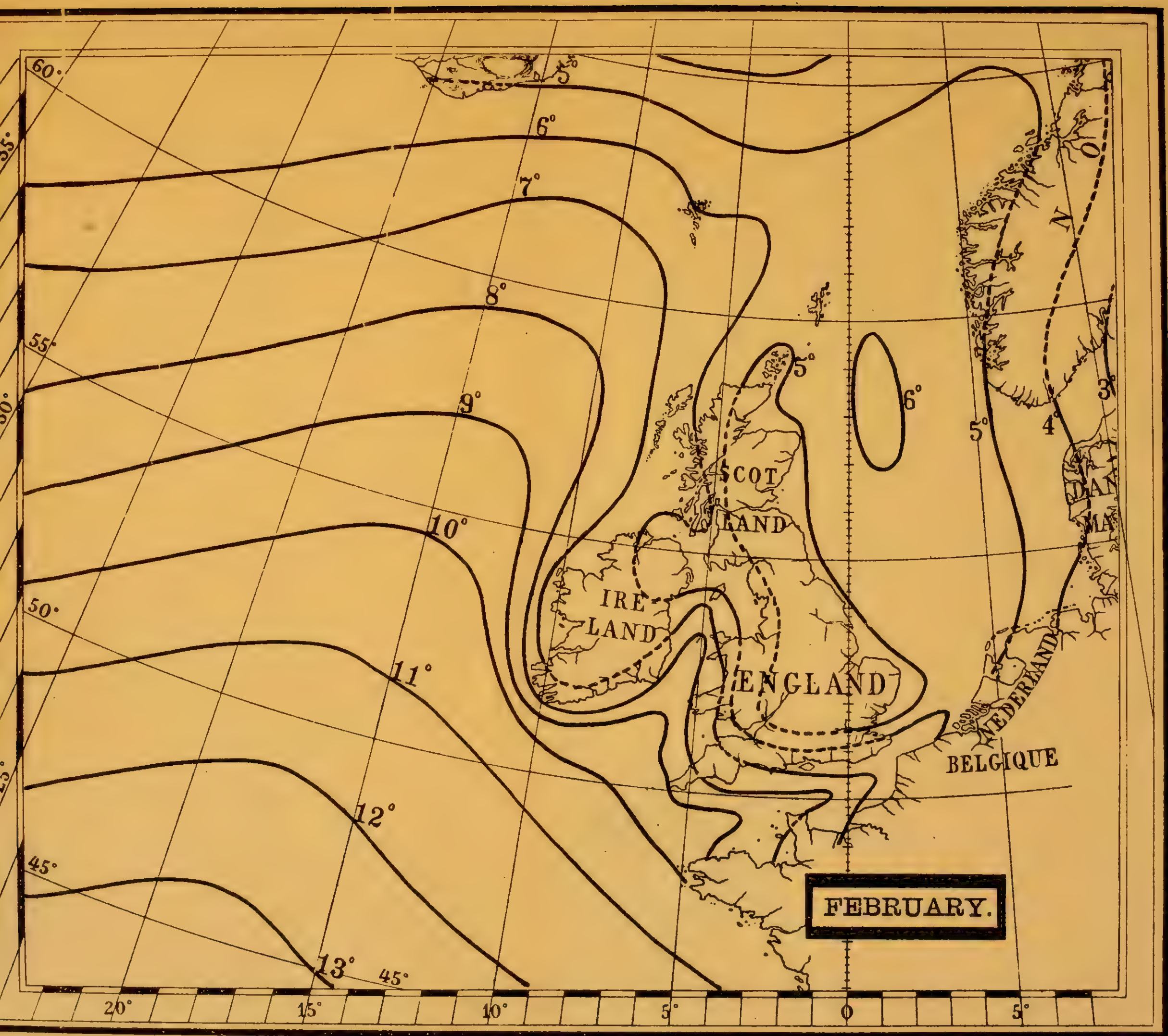

JANUARY.
SCOTLAND
IRELAND
ENGLAND
BELGIQUE
NEDERLAND
4°
5°
6°
7°
8°
9°
10°
11°
12°
13°
14°
60°
55°
50°
45°
35°
30°
25°
20°
15°
10°
5°
0

FIG. 13


FEBRUARY.
SCOT
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LAND
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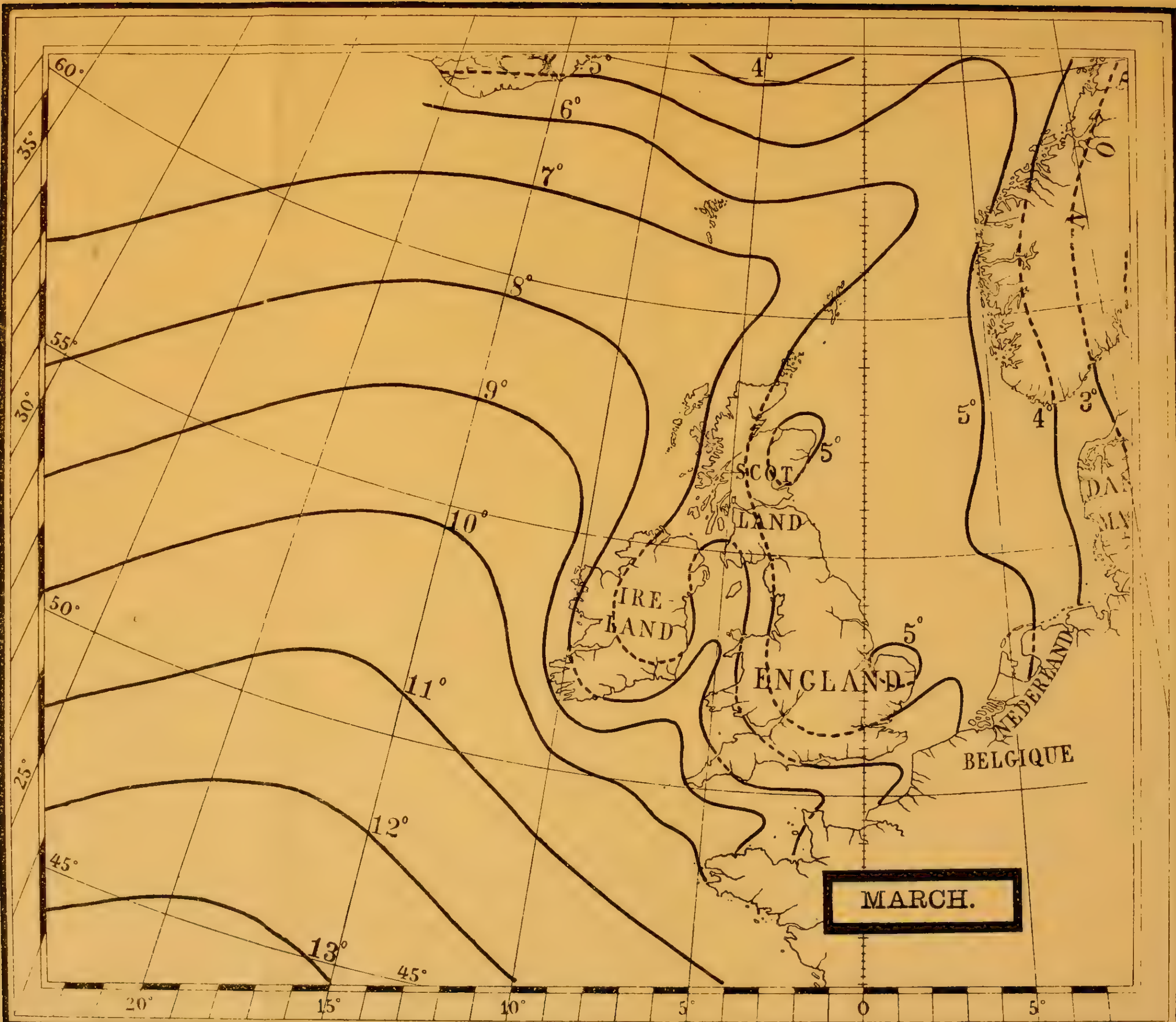
FIG.14.


MARCH.
SCOTLAND
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4°
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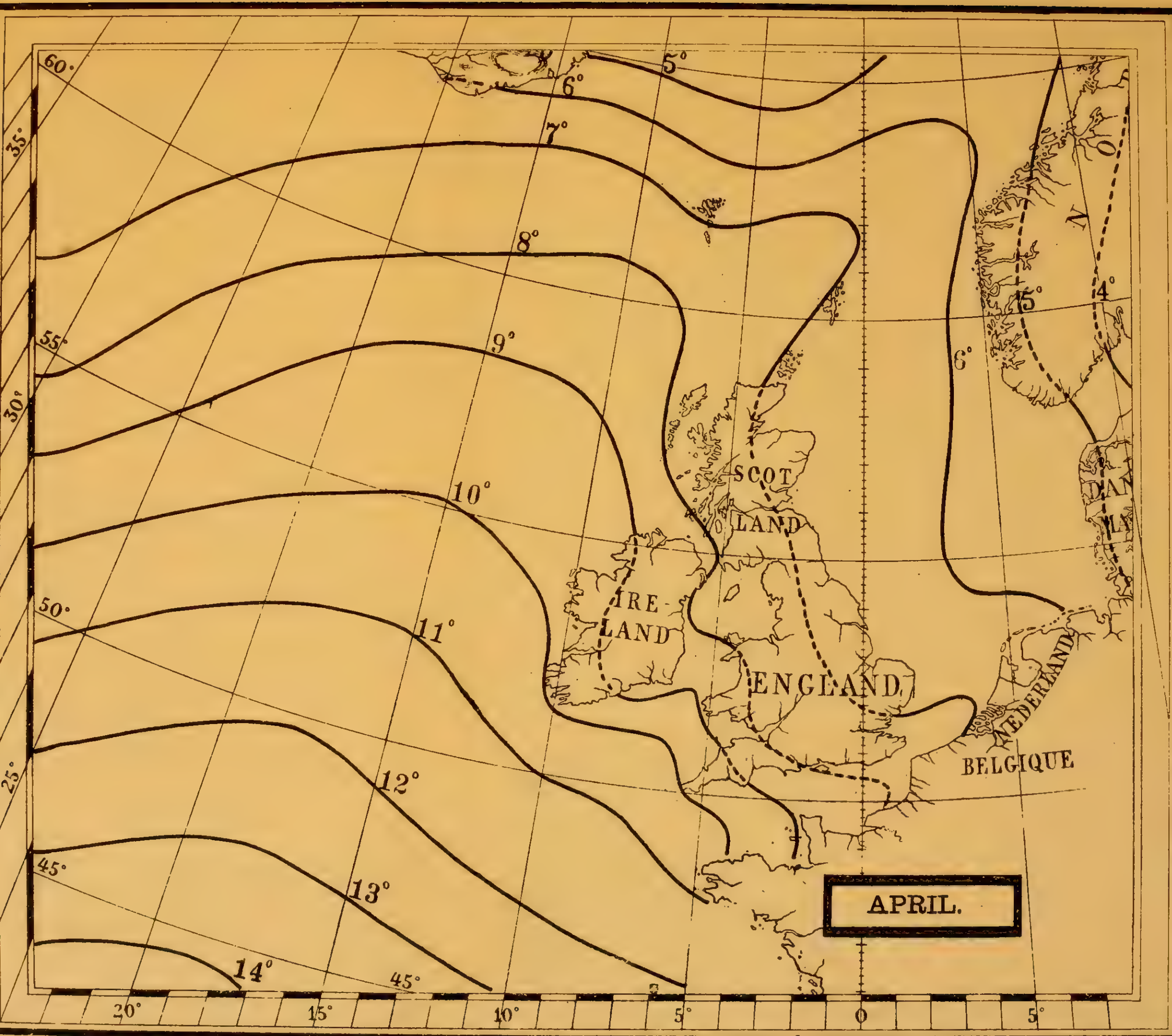
FIG 15



APRIL.
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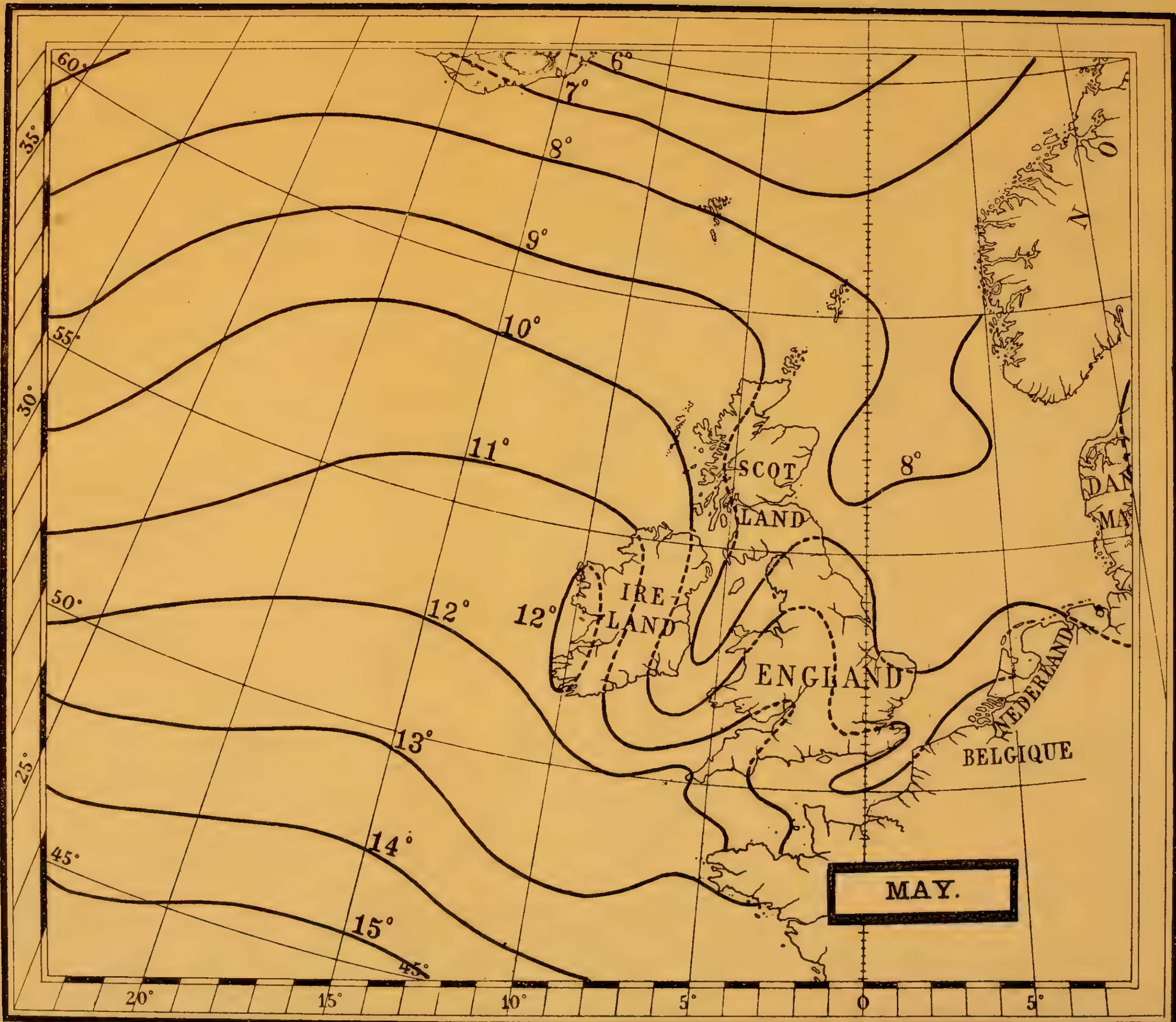
FIG.16.


6°
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SCOT
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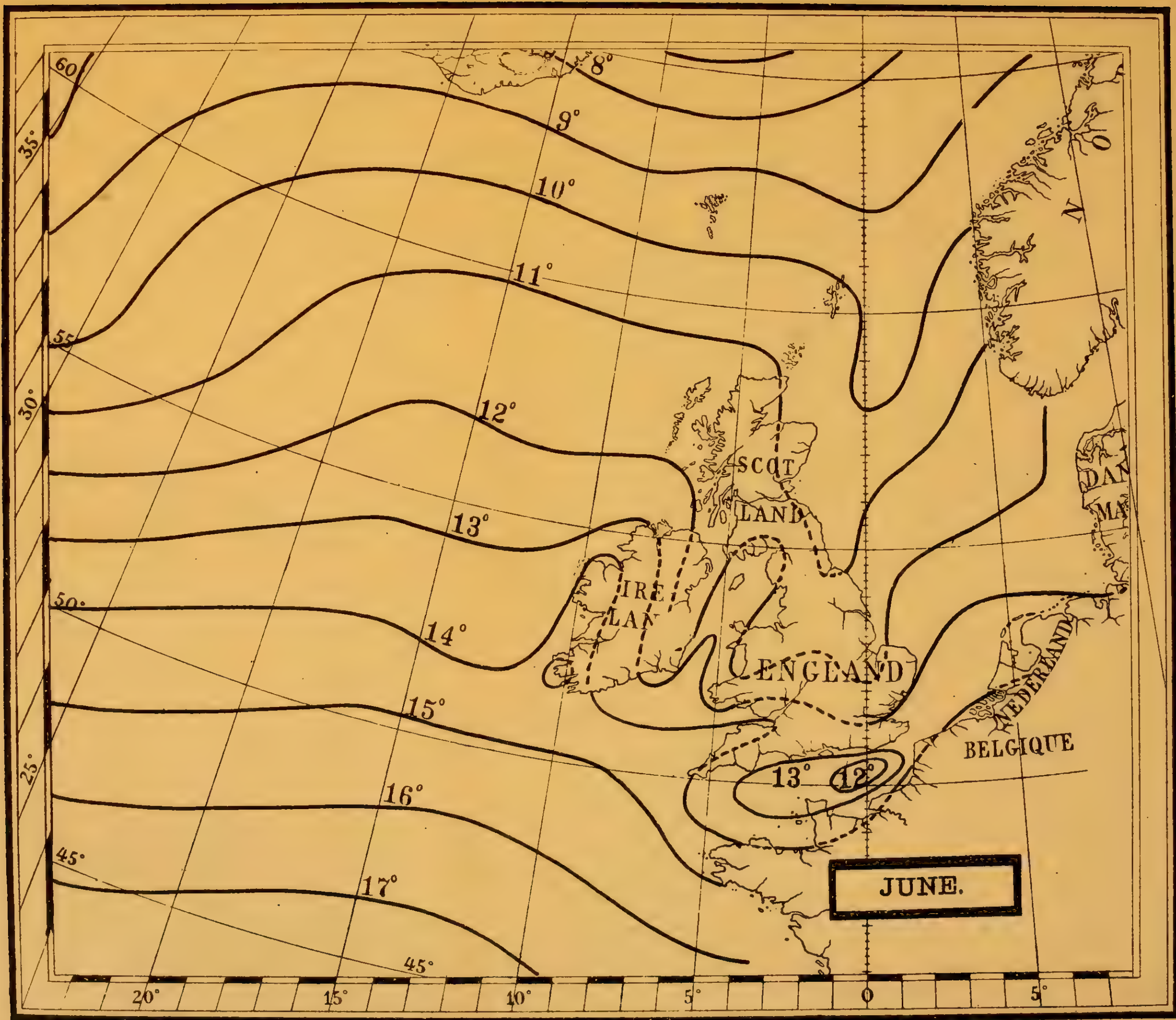
FIG. 17.



JUNE.
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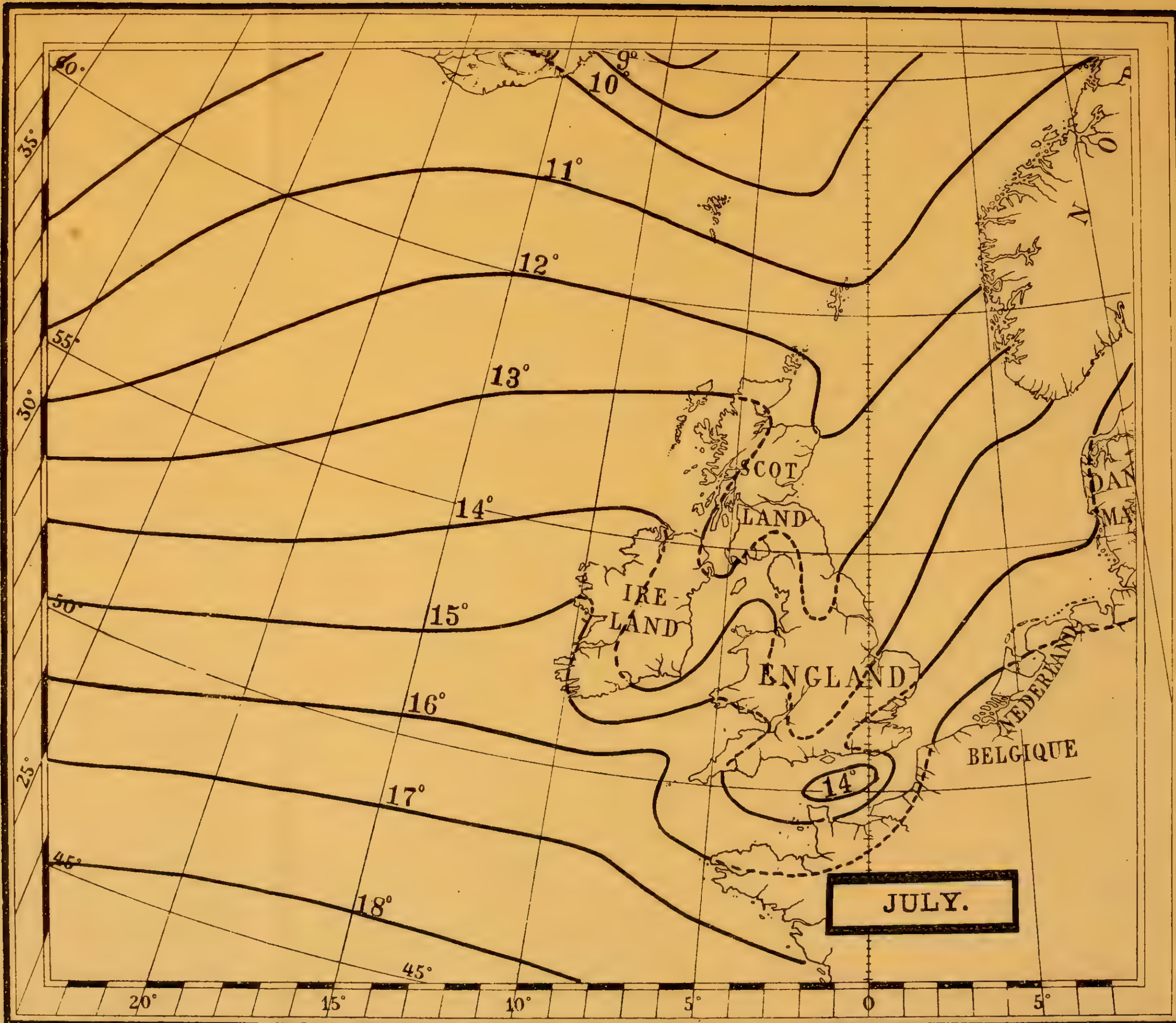
FIG.18.



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SCOT
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ENGLAND
NEDERLAND
BELGIQUE
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JULY.
20°
15°
10°
5°
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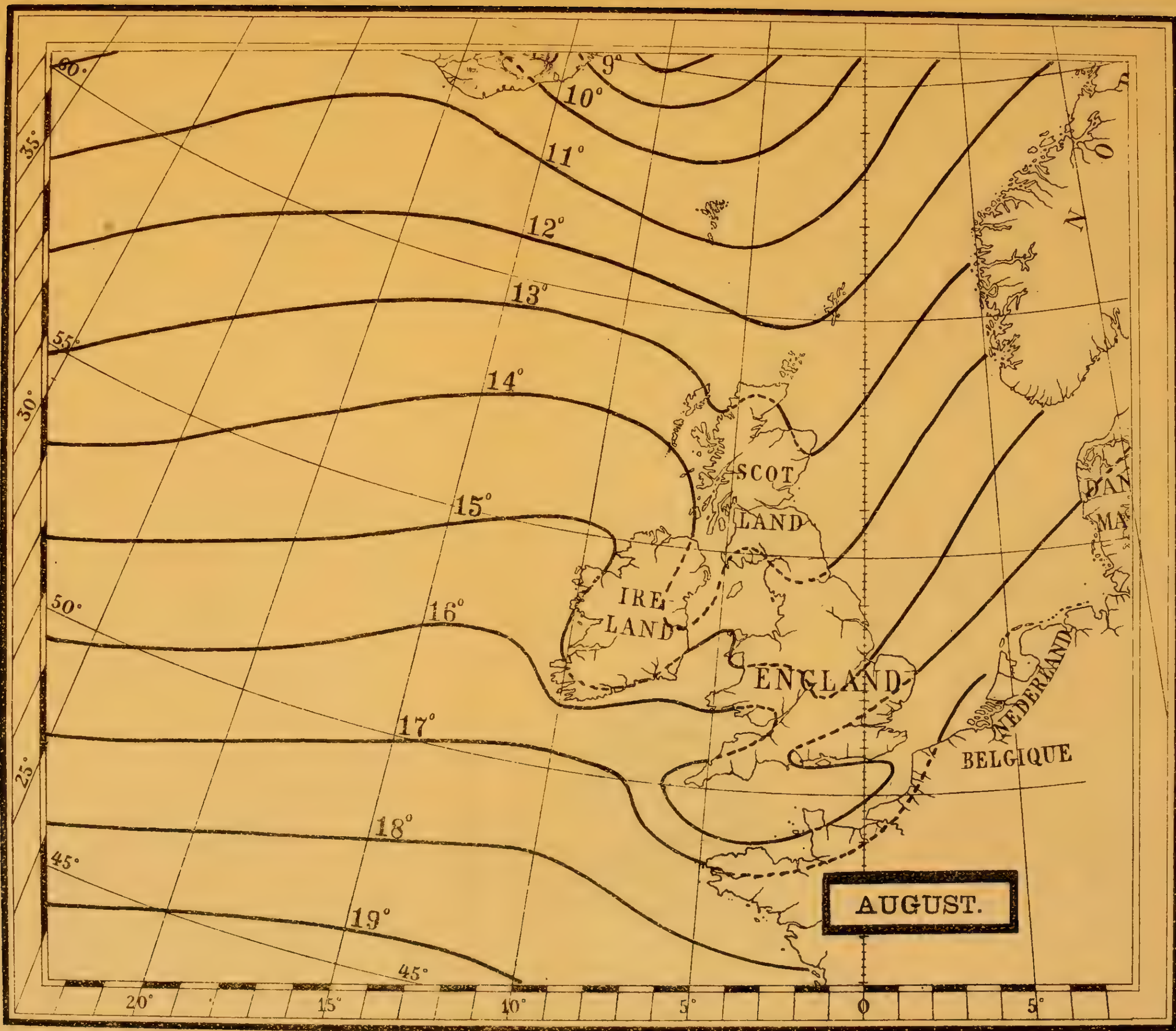
FIG. 19.



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SCOT
LAND
IRE
LAND
ENGLAND
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NEDERLAND
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AUGUST.
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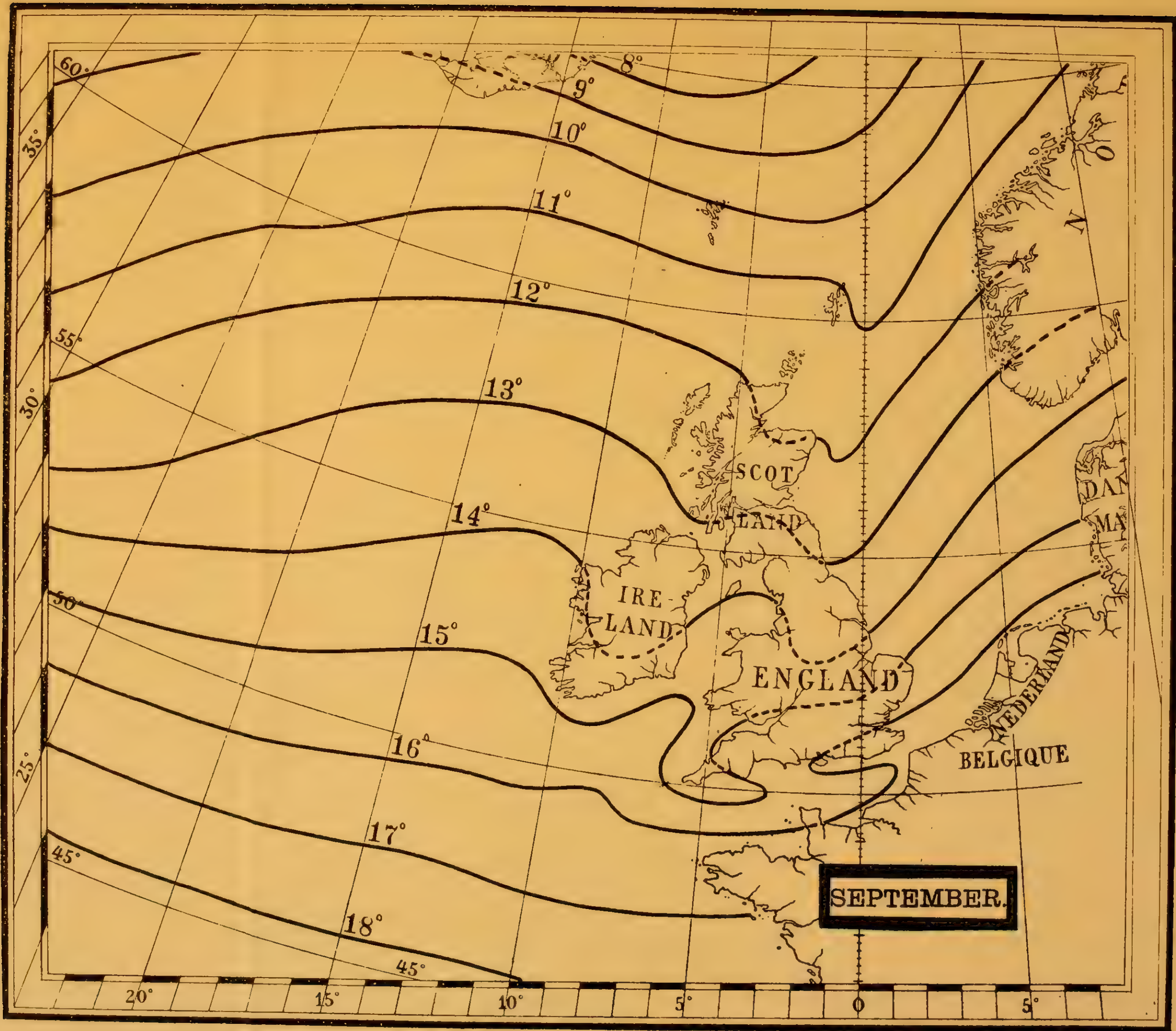
FIG.20.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SCOT
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ENGLAND
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SEPTEMBER.
20°
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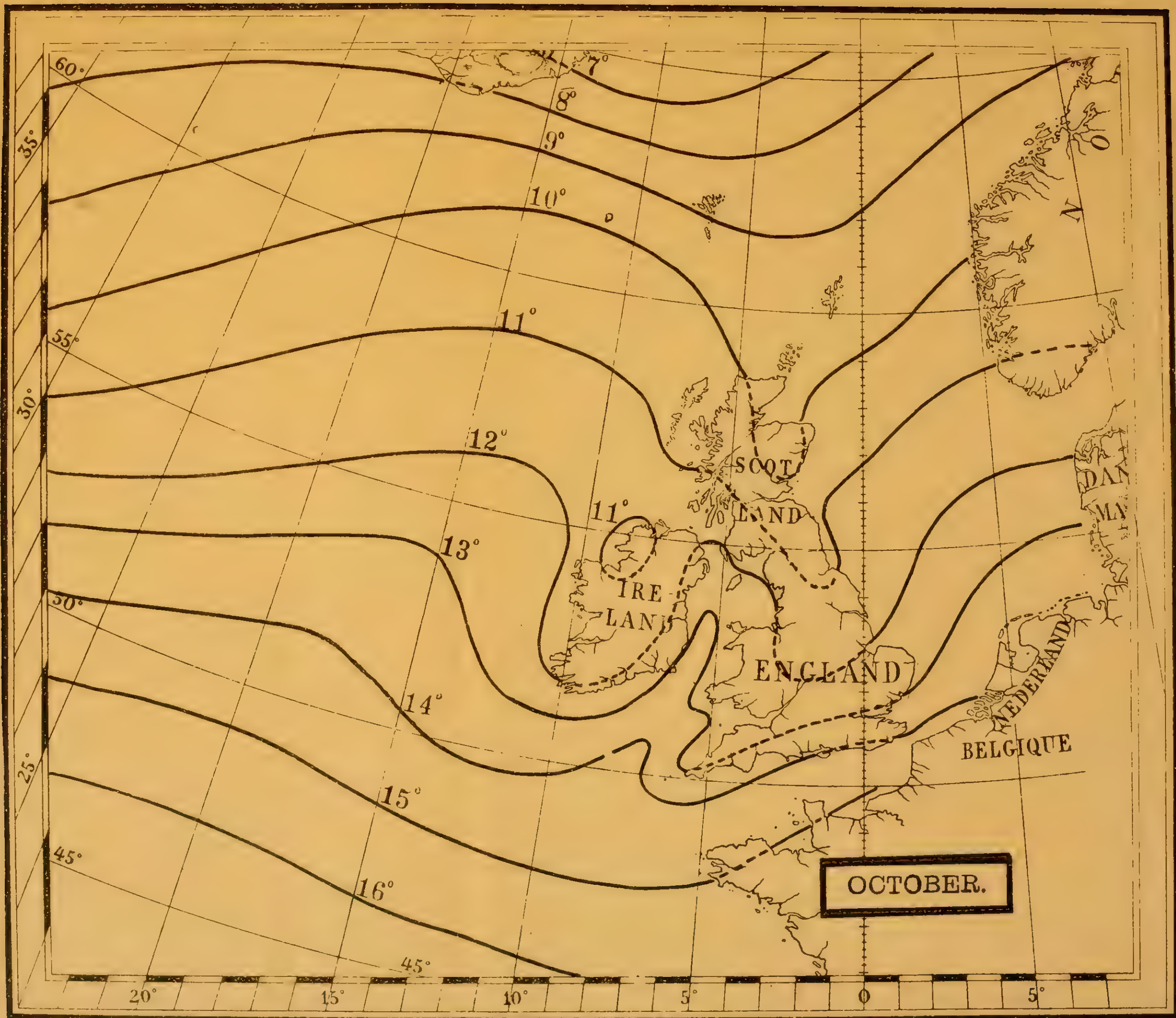
FIG. 21.



OCTOBER.
7°
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SCOTLAND
IRELAND
ENGLAND
BELGIQUE
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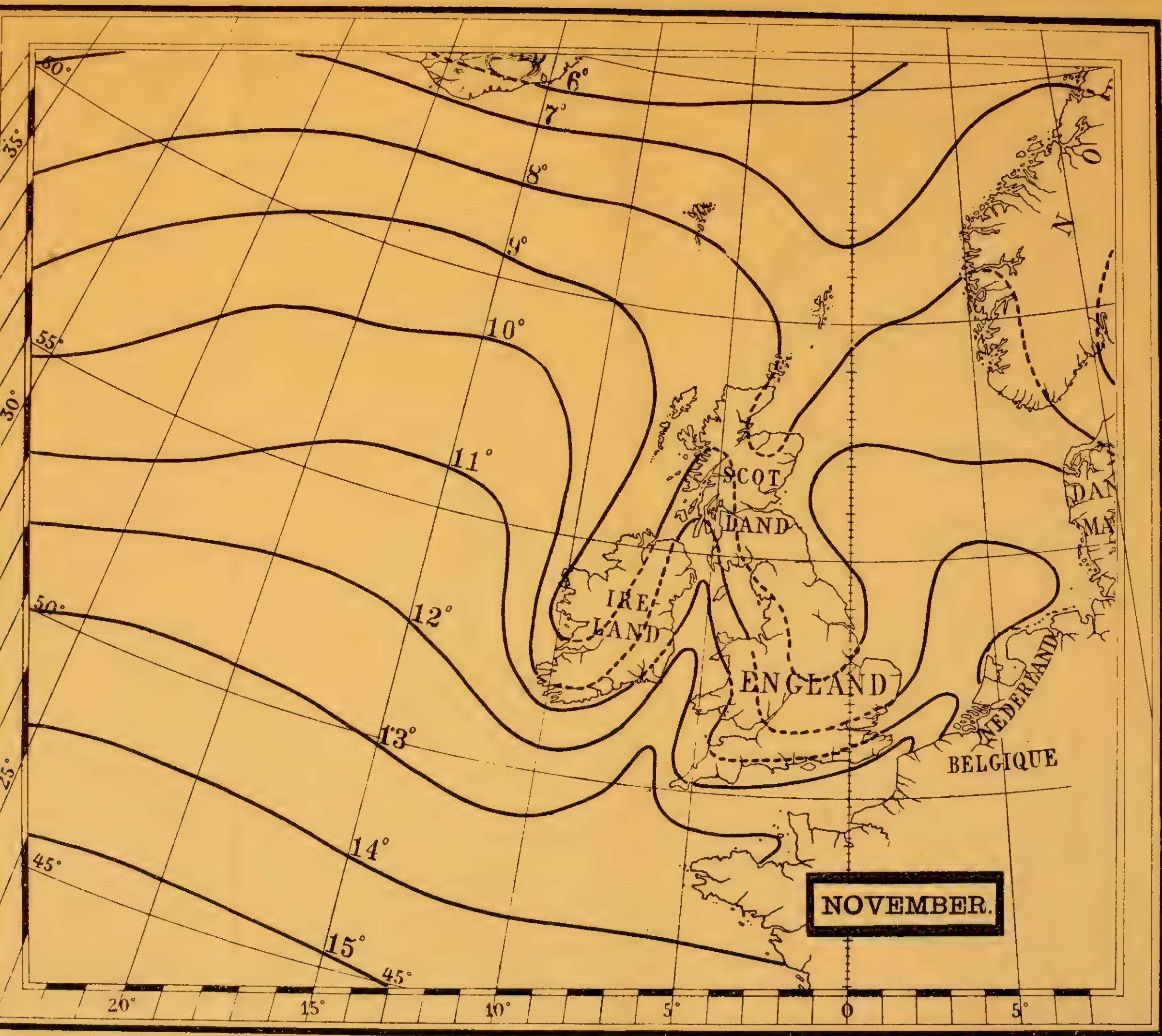
FIG. 22.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SCOT
LAND
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NOVEMBER.

FIG. 23.

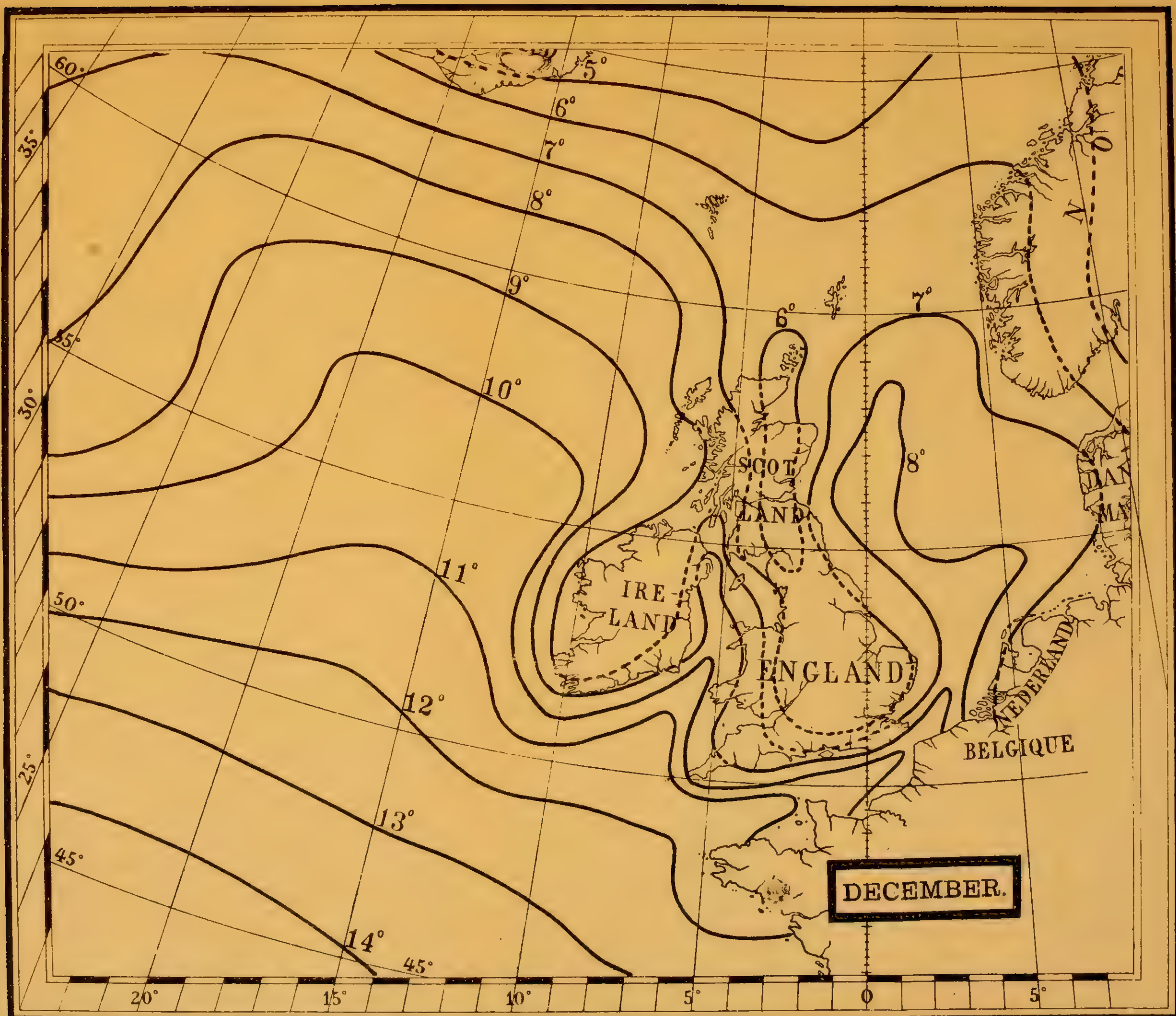

FIG. 24.

Looking in the first place at the former series, we see that in 20° W. and from about 45° N. to nearly 65° N. (that is to say, northwards to the coast of Iceland) we have a beautifully simple and

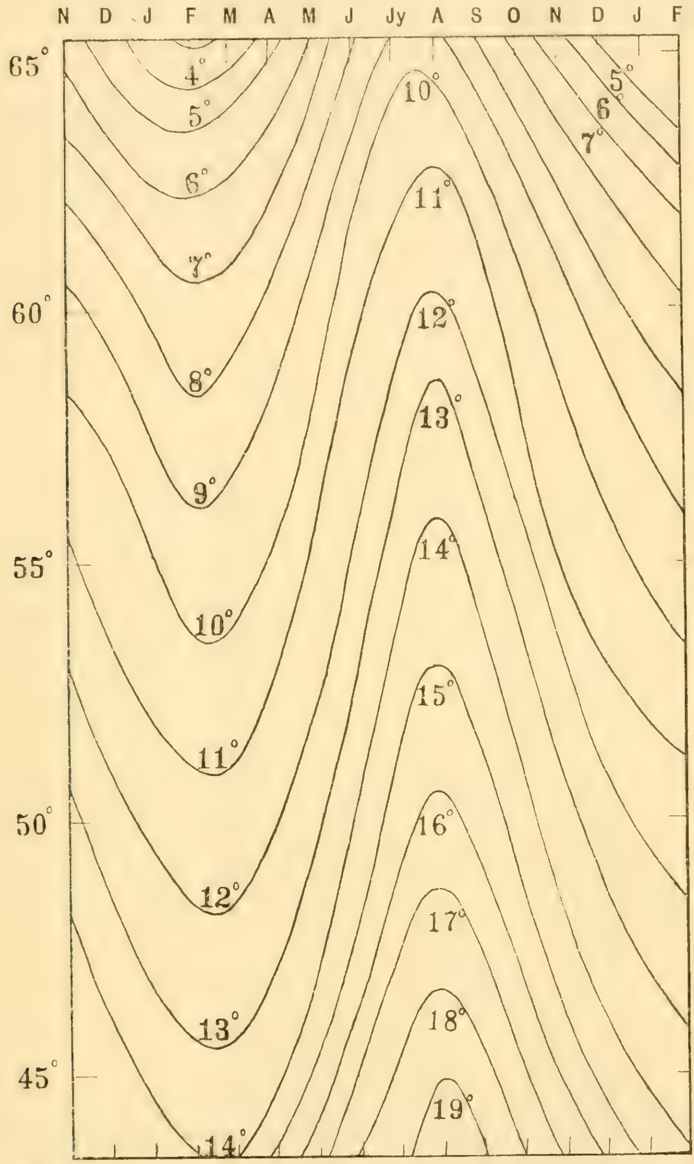

Fig. 25.—Surface-temperature fluctuations throughout the year, along the meridian of 20° W. longitude.

regular series of temperature phenomena (Fig. 25). We see at a glance the following features: (1) The contour-line for each degree centigrade forms approximately a sine-curve, with its summer maximum to the northward, and its winter or spring minimum to

the southward, of the line to which our data refer. (2) At the same time these curves are by no means symmetrical, but are considerably broader in the neighbourhood of their minima than of their maxima. (3) While there is a tendency to a crowding together of the curves as we go northward, or as the temperature falls, we see that this gradual

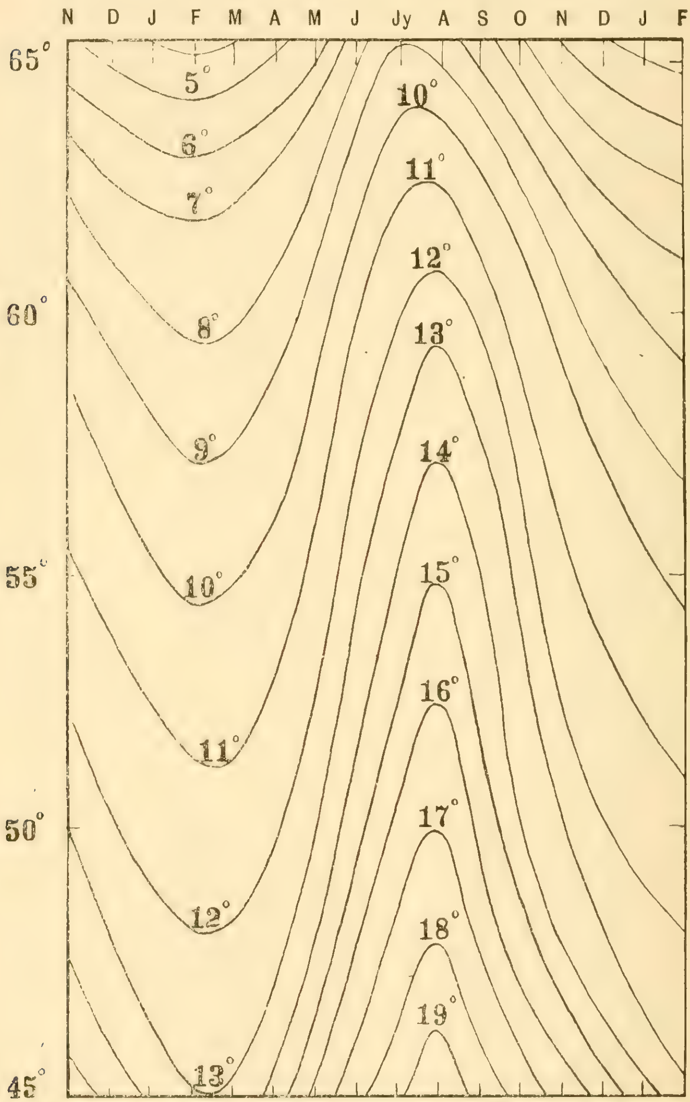

FIG. 26.—The same for 15° W.

tendency is evidently much more marked in the neighbourhood of the minima than of the maxima; in other words, the temperature gradient from south to north is more even, or less abrupt, in July and August than in early spring; at which latter season it tends to fall off rapidly in northern latitudes, *i.e.* in the neighbourhood of

Iceland. (4) We can distinctly trace a tendency to acceleration of phase as we pass northwards, the mean maximum temperature being apparently from a week to a fortnight earlier in the upper part of the diagram than in its southern portion.

The diagram for 15° W. (Fig. 26) shows no very important points

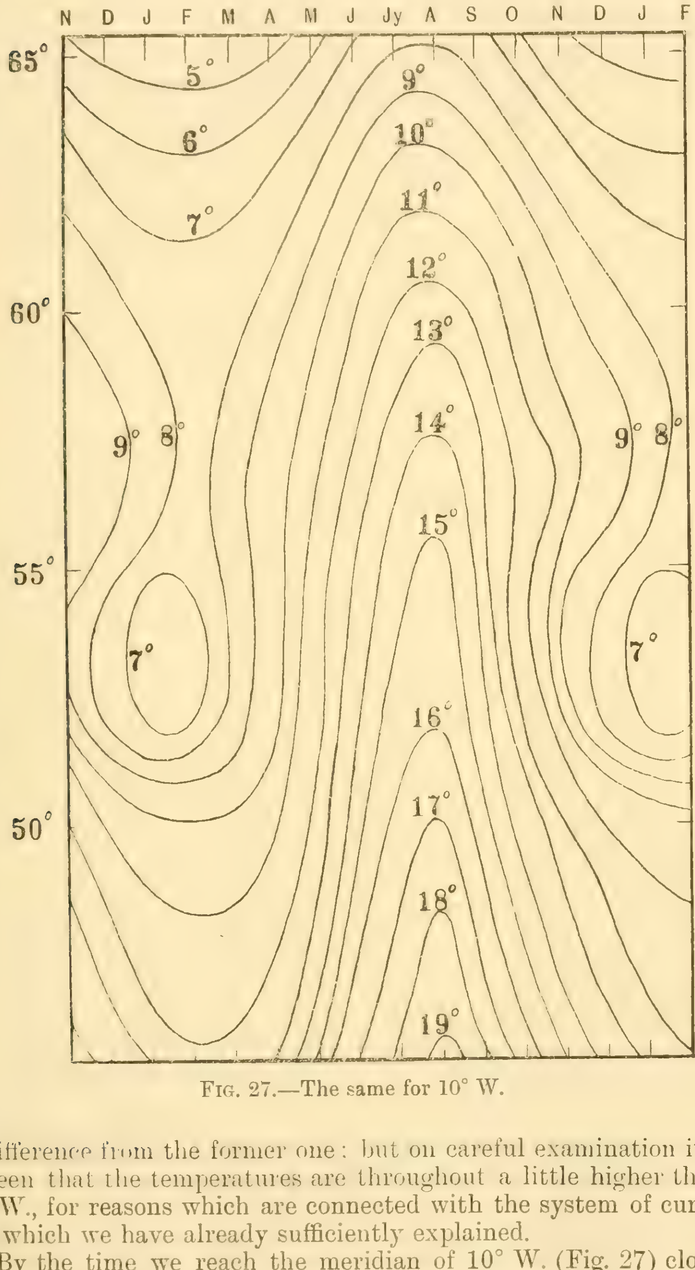

FIG. 27.—The same for 10° W.

of difference from the former one; but on careful examination it will be seen that the temperatures are throughout a little higher than at 20° W., for reasons which are connected with the system of currents and which we have already sufficiently explained.

By the time we reach the meridian of 10° W. (Fig. 27) close to the coast of Ireland (and indeed as this meridian cuts the Irish coast-

line our diagram must be taken to refer only approximately to the meridian itself), we see a somewhat marked change. Part of this change consists in a perceptible raising of the maximal temperatures in summer; but the lowering of the winter minima is very much more conspicuous and greatly affects the general appearance of our diagram. It is precisely off the west coast of Ireland, that is to

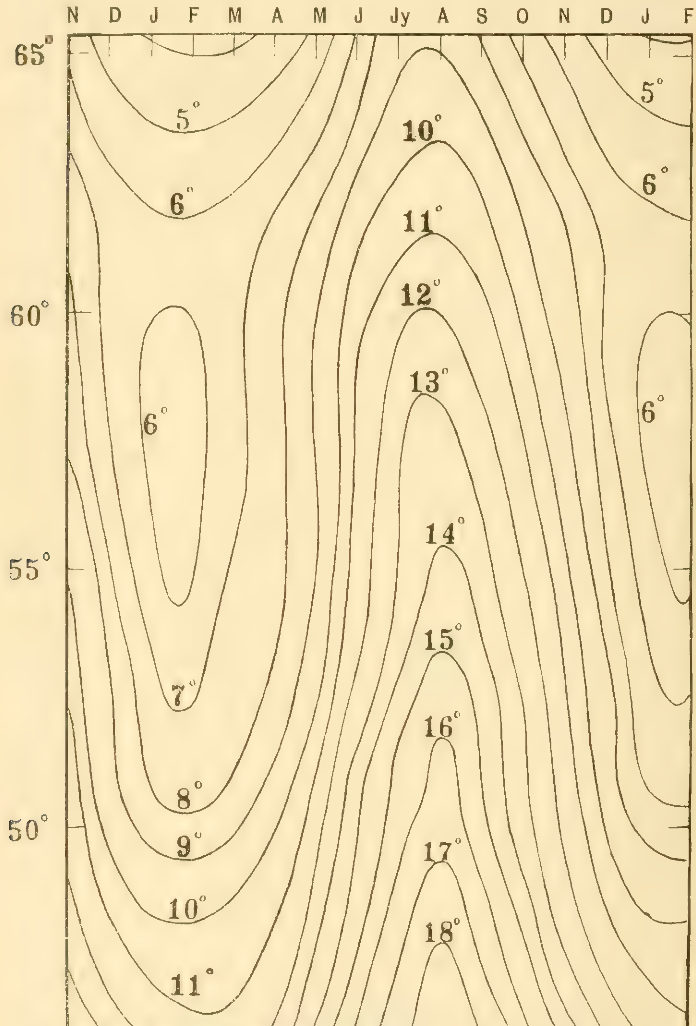

FIG. 28.—The same for 5° W.

say, between about 52° and 55° N., that these lowered minima are apparent, and cause a great departure from symmetry in our chart.

The diagram which refers, approximately, to 5° W. (Fig. 28) (approximately, since that meridian passes to a great extent over land, especially in the west of Scotland) has been built up from the

continuous isotherms of our temperature charts, as we have throughout drawn them by interpolation across the land from sea to sea; accordingly, this isopleth diagram of ours merely shows us in a diagrammatic way the conditions which exist in the adjacent waters, and those which would approximately exist along this particular meridian, if it were all converted into a water surface with as little change as possible in the distribution of the neighbouring land. We see here again, as in the former diagram, that low minima disturb the simple symmetry of the diagram, and that these are especially perceptible in the neighbourhood of the Scottish coast.

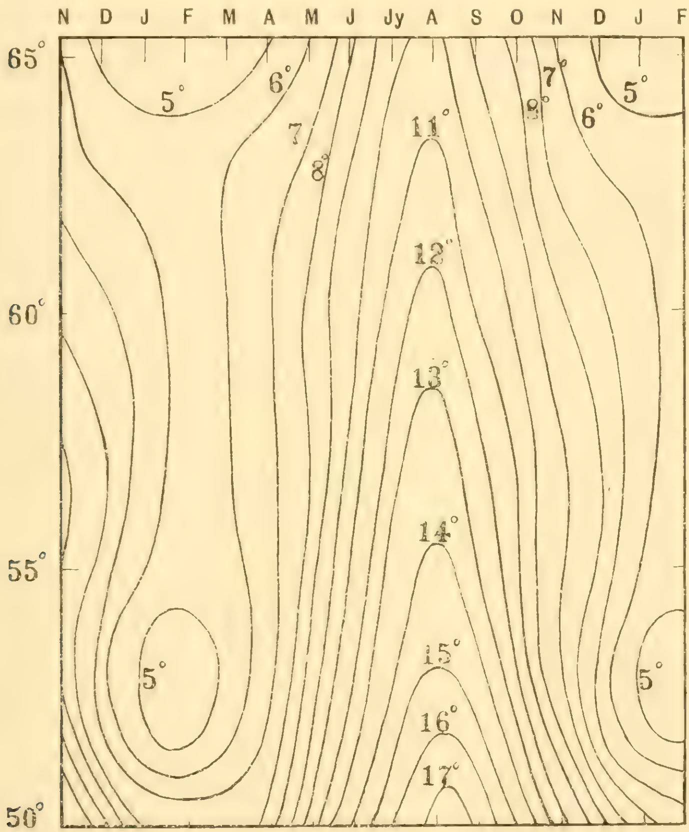

FIG. 29.—The same for longitude 0°.

Fig. 29, for the meridian of 0°, is again, in the same manner as Fig. 28, an artificial diagram; for this meridian crosses the land in the south-eastern and eastern counties of England. The diagram is closely comparable with the former ones, showing the same disturbance in regard to the minimal temperatures.

In 5° E. (Fig. 30), if we compare our diagram, for instance, with that for 5° W., various points of contrast will become apparent. Let it suffice here to point out (1) the still greater depression of the minima, (2) the fact that the chief depression appears where the line of the diagram lies nearest to the Norwegian coast, and lastly,

(3) the very marked increase in the maximal temperatures as compared with the more westerly line.

My last two diagrams (Figs. 31 and 32) represent (as I have already said) the same data as are shown in the corresponding diagrams of the foregoing series, but translated here into the form of "anomalies," or differences as compared with the conditions of the meridian of 15° W. In the case of the meridian of 10° W. (Fig. 31), the diagram has two vertical axes of symmetry, one in January, the other in July, corresponding approximately to the seasons of maximal and minimal temperature. It will be noticed at once that the

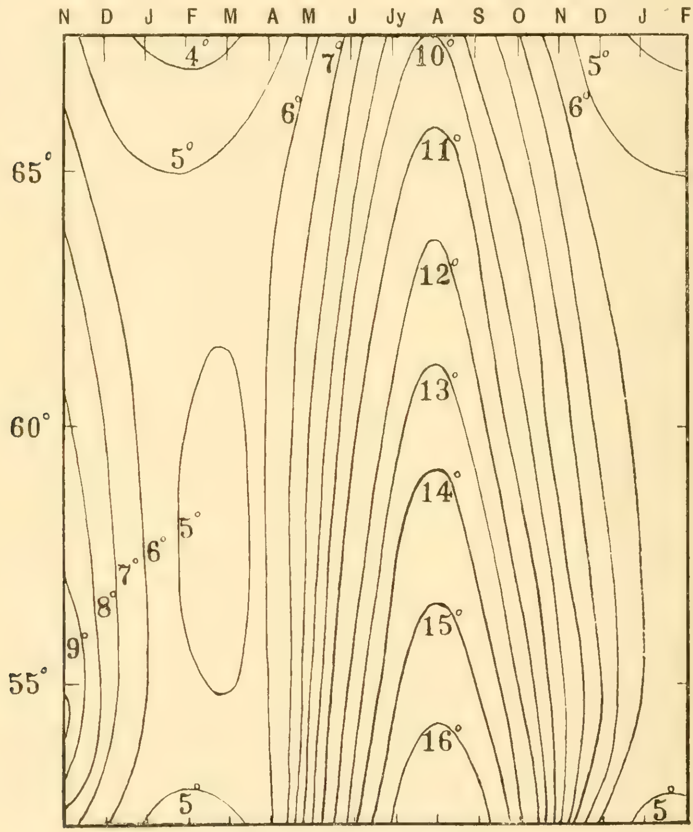

Fig. 30.—The same for 5° E.

largest departures from the temperatures of oceanic standard of comparison lie a little to the southward of 55° N., that is to say, where the line of the diagram comes closest to the Irish coast. Here, in summer time, the surface temperature of the sea is about half a degree centigrade higher than in the open ocean, five degrees to the westward; but in winter time the sea temperature is over two degrees colder than in this latter meridian. In the upper half of our diagram, north of 57° or 58° N., and therefore free of the coastal influence of the British Islands, the temperature differences from the more westerly meridian are extremely small, being less than half a

degree higher in summer and less than half a degree lower in winter.

Fig. 32, representing the anomalies of the meridian of 0°, illustrates a number of points which will be more or less obvious to the reader, but which might lead us into a long discussion were I to attempt to describe them in detail. The most important points

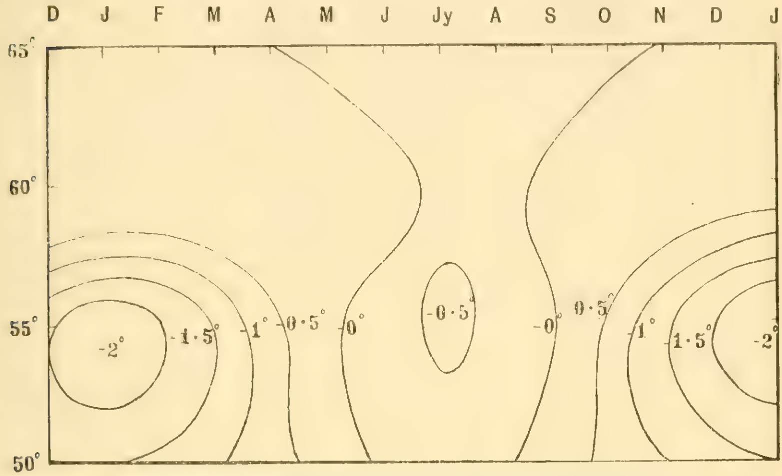

Fig. 31.—Surface-temperature fluctuations along the meridian of 10° W. compared with those in 15° W.

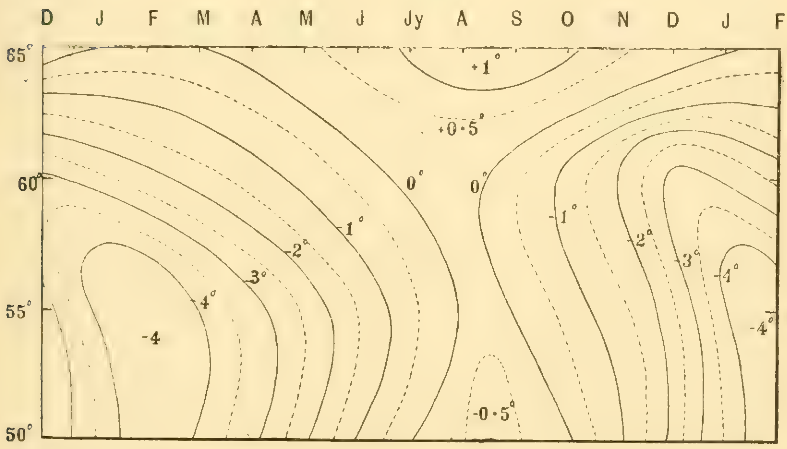

Fig. 32.—Surface-temperature fluctuations along the meridian of 0°, reduced to the same standard of comparison, viz. 15° W.

appear to be the following: (1) an asymmetry of the whole diagram, which will be easily recognised as due to a phase difference between the southern and northern portions of the meridian represented; (2) the slight excess of maximal temperature to the southward, and the somewhat greater excess of maximal temperature near the northern border of the diagram. The latter portion of the phenomenon is not so much due to any positive conditions in the meridian

of 0°, but rather to the fact that in this region the temperatures of our standard meridian were unduly depressed by proximity to the great cold land-mass of Iceland; (3) the very marked lowering of the minimal temperatures, especially in the southern half of the diagram, that is to say, where the line passes through the North Sea.

There are many other matters connected with the surface temperature phenomena of our seas, and many other facts contained in our tables and our diagrams, which might be dwelt upon at much greater length and further illustrated in various ways. For instance, I have not attempted to describe, or to discuss in words the various special phenomena which, at various seasons, characterise one portion or another of our coasts. These various phenomena will, for the most part, be obvious enough to any careful student of our charts. It will be time enough for a more detailed discussion when our observations have become more numerous, and all our facts are better established. Let me remark, in conclusion, that, while all the charts and diagrams in this paper are to be regarded as no more than first approximations to the truth, drawn to the best of my own powers from the somewhat scanty data which are all that we have as yet, this is especially true of the isopleth diagrams (Figs. 25–32) which we have just been discussing. These are to be clearly understood as diagrammatic or simplified representations of much more complicated phenomena. As a matter of fact, these isopleth diagrams were all drawn before I made my last revision of the maps on which they are based, and to embody our last corrections in them would have involved redrawing the whole series. None of the corrections are such as to interfere with the general truth of the diagrammatic picture; but it is possible that a careful reader may here and there discover some slight discrepancy between these diagrams and the isotherms of our twelve monthly charts.

TABLE I.—MEAN MONTHLY AND ANNUAL TEMPERATURE OF SURFACE WATERS. British Lightship and Coastguard Stations: after Dickson (reduced to Centigrade scale).

Station.	No. of Years.	Years Specified	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
ENGLAND.															
Sunderland	17	1880–96 .	4·83	5·00	5·40	6·94	9·22	11·94	13·33	13·78	12·83	9·72	7·67	5·50	8·89
Scarborough	12	1880, 81, 83, 84, 90–97	4·83	4·83	6·00	7·61	10·00	12·44	13·83	14·67	13·39	10·72	7·67	5·56	9·28
Spurn	13	1880–84, 90–97	4·39	4·56	5·33	6·83	9·33	12·44	14·28	14·78	13·94	11·22	8·39	6·00	9·28
Outer Dowsing . . .	18	1880–97 .	5·33	4·89	5·00	6·22	7·94	11·39	13·44	14·00	13·72	11·78	9·33	7·28	9·17
” ” . . .	27	1880–1906 .	5·65	5·15	5·20	6·60	8·60	11·30	13·35	14·25	13·95	11·85	9·50	7·35	9·15
Leman and Ower . . .	18	1880–97 .	4·94	4·39	4·72	6·17	8·67	11·72	14·06	15·06	14·39	12·06	9·39	6·83	9·39
Newarp	15	1880–85, 87, 88, 90–95, 97	4·56	4·22	4·72	6·39	8·94	12·06	14·67	15·61	14·94	12·33	9·28	6·39	9·50
Shipwash	15	1880–86, 88–90, 93–97	4·44	4·28	5·11	6·94	9·89	13·22	16·00	16·94	16·00	12·78	9·56	6·61	10·17
Goodwin	18	1880–97 .	6·61	6·33	6·44	7·83	10·39	13·33	15·61	16·83	16·50	13·89	11·61	9·00	11·17
Varne	10	1904–14 .	7·9	6·7	6·75	7·7	9·85	12·3	14·4	15·8	16·0	14·7	13·9	10·1	11·34
Royal Sovereign . . .	18	1880–97 .	6·78	6·06	6·22	7·78	10·22	13·00	15·50	16·67	16·33	14·11	11·56	9·00	11·11
Owers	17	1881–97 .	7·06	6·39	6·39	7·61	10·11	13·17	15·67	16·67	16·22	14·06	11·56	9·00	11·17
Shambles	17	1881–97 .	7·72	7·06	6·94	8·00	10·06	12·72	14·67	16·06	15·94	14·11	11·78	9·56	11·22
Salcombe	17	1880–86, 88–97	7·44	7·39	7·61	8·94	11·11	13·44	14·78	15·39	15·06	13·00	11·06	8·89	11·17
Falmouth	14	1872–85 .	8·89	8·61	8·78	9·61	11·11	13·06	14·44	15·39	15·00	13·67	11·67	9·83	11·67
Scilly	11	1887–97 .	9·33	8·78	9·50	10·44	12·28	14·56	15·61	15·61	14·94	13·06	11·50	10·28	12·17

TABLE I.—Mean Monthly and Annual Temperature of Surface Waters. British Lightship and Coastguard Stations: after Dickson (reduced to Centigrade scale)—*continued.*

Station.	No. of Years.	Years Specified.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
England—*continued.*															
Seven Stones	13	1881–85, 89, 91–97	9·94	9·44	9·22	9·72	11·00	13·17	15·22	15·61	14·89	13·33	12·28	11·06	12·06
" " *	10	1904–14	10·08	9·45	9·14	9·63	10·76	12·93	15·13	15·71	14·97	13·40	12·21	11·06	12·04
Newquay	7	1891–97	6·83	7·28	8·11	9·83	12·17	14·61	16·39	16·44	15·28	12·83	10·50	8·78	11·56
Padstow	8	1880–87	7·28	7·83	9·89	9·28	11·72	14·44	16·28	16·61	15·44	12·67	10·39	14·06	11·50
Newquay and Padstow	15	1880–87, 91–97	7·06	7·56	8·00	9·56	11·94	14·50	16·33	16·50	15·33	12·78	10·44	8·61	11·50
English and Welsh Grounds	18	1880–97	4·56	4·67	5·72	8·00	11·33	14·72	17·17	17·39	15·89	12·34	8·89	6·39	10·83
Helwick	2	1880–81	5·89	5·56	6·50	7·83	10·33	12·56	15·33	16·56	15·83	13·11	10·67	8·89	10·78
	—	Mean	7·28	6·06	5·67	7·78	10·00	12·67	15·22	16·61	15·94	13·56	11·11	8·28	10·83
St. Ann's Head, Pembroke	10	1872–77, 91–97	7·78	7·33	7·61	8·67	10·33	12·50	14·39	14·94	14·44	12·89	11·22	9·72	11·00
Cardigan Bay	12	1881, 82, 84, 89–97	7·72	7·39	7·39	8·11	9·50	11·67	13·28	14·44	14·33	12·94	11·28	9·39	10·61
Carnarvon Bay	18	1880–97	7·94	7·22	7·00	7·67	9·17	11·28	13·06	14·17	14·50	13·17	11·33	9·33	10·50
Holyhead Old Pier	11	1887–97	6·22	5·89	6·44	7·89	10·11	12·83	14·89	15·17	14·61	12·50	10·33	7·72	10·39
N.W.L.V., Liverpool B.	16	1880–81, 83–91, 93–97	5·61	5·28	5·61	7·28	9·50	12·50	15·11	15·89	15·17	12·17	9·56	7·28	10·06
Bahama Bank	18	1880–97	6·11	5·83	6·11	6·83	8·89	11·78	13·28	14·28	14·11	12·28	9·83	7·61	9·72
Solway	13	1885–97	3·83	4·11	4·89	7·33	10·78	13·94	15·72	15·67	13·89	10·50	7·61	5·33	9·44
Scotland.															
Ballantrae	18	1880–97	5·78	5·67	6·11	7·50	9·89	12·17	13·89	14·00	13·22	10·33	8·44	6·72	9·44
Lamlash, Arran	18	1880–97	6·39	6·22	6·33	7·56	9·67	12·22	13·61	13·83	12·89	10·50	8·94	7·39	9·61

Ailsa Craig †	10	1904–13	7·18	6·52	6·31	7·91	8·96	11·63	13·38	13·82	12·72	11·88	10·04	8·53	9·83
Oban	?	?	7·78	6·67	6·11	7·22	8·33	11·44	12·22	12·78	12·78	11·67	10·00	8·33	9·61
Bernera	?	?	7·94	6·11	6·39	7·22	8·89	11·67	12·78	12·78	12·22	10·83	8·89	7·78	9·44
Harris	5	1858–63	7·06	6·33	6·39	7·06	8·83	11·06	12·67	13·00	12·28	10·89	9·06	8·00	9·39
Harris and Bernera	?	?	7·50	6·22	6·29	7·11	8·89	11·33	12·72	12·89	12·22	10·83	9·00	7·89	9·44
Stornoway	13	1883–88, 91–97	4·89	5·50	5·72	7·91	10·56	13·44	14·61	11·28	12·83	9·50	7·22	5·44	9·33
"	35	1859–80, 83–88, 91–97	5·91	5·50	6·33	7·91	9·11	12·33	13·78	13·72	12·72	10·33	8·28	6·78	9·39
Lerwick	18	1880–97	5·89	5·61	5·39	6·61	8·39	10·11	11·72	12·11	11·28	9·50	7·78	6·44	8·39
Kirkwall	17	1880–86, 88–97	4·78	4·83	5·06	6·91	8·83	10·94	12·33	12·61	11·72	9·22	7·33	5·72	8·39
Wick	11	1880–83, 87, 92–97	6·00	5·89	5·94	6·94	8·56	10·33	12·00	12·33	11·72	10·50	8·78	7·17	8·72
Cromarty	17	1881–97	4·00	3·89	4·67	6·39	9·17	12·50	13·78	13·67	11·67	9·28	7·00	5·00	8·44
Fraserburgh	5	1883–87	4·50	4·61	4·72	6·00	10·06	10·56	12·94	12·94	11·89	9·28	7·00	5·06	8·11
Pennant	8	1889–93, 95–97	4·44	4·00	5·06	6·72	9·06	11·50	12·89	13·28	12·11	9·50	6·89	5·17	8·39
Fraserburgh and Pennant (Corr.)	13	1883–87, 89–93, 95–97	4·44	4·22	4·94	6·44	8·61	11·11	12·89	13·17	12·06	9·39	6·91	5·11	8·28
Rattray Head †	10	1904–13	5·49	4·83	5·01	6·10	8·09	10·31	12·23	12·73	11·91	10·39	8·50	6·81	8·53
Peterhead	7	1873–79	5·44	4·94	4·83	5·83	7·67	10·22	12·28	12·83	12·33	10·94	8·50	6·50	8·56
Aberdeen, Cove B.	18	1880–97	5·56	5·33	5·44	6·17	7·67	9·89	11·83	12·33	11·61	9·89	8·44	6·94	8·44
Uzon, Montrose	15	1883–97	4·67	4·83	5·39	6·94	8·67	10·78	12·83	13·17	12·06	9·72	7·61	5·72	8·50
Abertay L.V.	7	1880–86	4·39	3·94	4·22	6·00	8·33	11·33	13·39	13·28	12·39	10·17	7·83	5·50	8·39
" " †	10	1904–13	5·29	4·64	4·94	6·23	8·26	10·68	12·67	13·21	12·48	10·87	8·44	6·59	8·69
North Carr †	10	1904–13	5·92	5·02	5·10	6·09	8·08	10·51	12·43	12·99	12·17	11·12	8·96	7·14	8·79
Burntisland	18	1880–97	4·61	4·50	4·94	6·39	8·83	11·72	13·06	13·00	12·50	10·06	7·67	5·67	8·56
Dunbar	9	1857–65	5·22	4·61	5·06	6·72	9·22	11·22	13·17	13·50	12·89	10·61	8·11	6·61	8·89
Burnmouth	9	1889–97	5·22	4·94	5·22	6·61	8·72	11·22	12·83	13·28	12·44	10·33	8·50	6·28	8·78

* From Mr. E. C. Jee. † From data collected for the Scottish Fishery Board.

TABLE I.—MEAN MONTHLY AND ANNUAL TEMPERATURE OF SURFACE WATERS. British Lightship and Coastguard Stations: after Dickson (reduced to Centigrade scale)—*continued.*

Station.	No. of Years.	Years Specified.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
IRELAND.															
Kish Bank	14	1881–82, 85–90, 92–97	6·67	6·56	6·39	7·14	9·50	12·11	13·50	13·94	13·44	11·61	10·11	8·44	10·00
Coningbeg	15	1882, 84–97	8·17	7·72	7·72	8·39	9·78	11·89	13·39	14·11	14·17	12·89	11·28	9·39	10·72
Daunt's Rock	15	1880–82, 85–96	7·89	7·89	7·94	8·83	10·67	13·00	13·78	14·11	14·06	12·28	10·50	9·17	10·83
Castletownshend	7	1880–85, 87	7·22	7·22	8·44	9·78	12·06	14·22	15·06	15·56	14·06	11·17	9·44	8·00	11·06
Minard, Dingle Bay	16	1880–84, 87–97	7·06	7·44	7·67	9·78	12·39	15·00	15·72	15·56	14·28	11·22	8·94	7·67	11·06
Seafield	7	1891–97	6·50	6·61	8·00	10·11	12·61	15·39	15·94	15·33	14·11	10·83	8·83	7·78	11·06
Liscannor	7	1880–4, 96–7	6·67	7·50	8·28	9·56	11·94	14·06	15·80	15·83	14·39	11·44	9·28	7·44	11·00
Aran, N. Island	9	1889–97	6·83	6·89	7·78	9·56	12·06	14·72	15·72	15·72	14·78	11·67	9·44	7·67	11·00
Cleggan	17	1881–97	7·00	7·17	7·72	9·22	11·33	13·44	14·50	14·67	13·78	11·11	9·33	7·78	10·61
Blacksod Point	7	1881, 85–90	5·67	6·61	7·50	9·83	12·78	15·17	15·89	15·56	14·06	10·50	8·39	6·89	10·72
Claggan	7	1881, 85–90	5·78	6·00	6·94	9·33	12·39	15·11	16·06	15·78	14·22	10·89	9·06	6·61	10·67
Ballyglass	18	1880–97	6·83	7·11	7·72	9·33	11·33	13·67	14·83	14·94	13·89	11·06	9·17	7·61	10·61
Killybegs	5	1880–84	5·67	6·11	7·11	9·17	12·06	14·78	15·83	15·94	14·67	10·89	8·00	6·28	10·56
Teelin	9	1889–97	6·00	6·17	7·06	8·83	11·06	14·11	14·50	14·67	13·61	10·39	8·33	6·67	10·11
Dunfanaghy	18	1880–97	6·11	6·11	6·61	8·22	10·44	12·94	14·33	14·61	13·33	10·89	8·94	7·06	9·94
Portrush	18	1880–97	5·61	5·78	6·22	7·67	9·78	12·28	13·78	14·11	13·17	10·67	8·17	6·50	9·44
Cushendall	?	?	8·11	7·61	7·56	8·44	9·50	11·17	13·00	13·89	14·61	13·11	10·89	9·67	10·78
Donaghadee	?	?	8·06	7·56	7·56	8·94	10·17	11·39	13·22	14·11	14·17	12·61	10·06	9·61	10·56
South Rock	18	1880–97	8·17	7·50	7·28	7·83	9·22	10·89	12·22	13·17	13·44	12·61	11·33	9·72	10·28

TABLE II.—HARMONIC CONSTANTS OF MEAN SURFACE TEMPERATURES AT BRITISH COASTAL STATIONS.

	A_0.	A_1.	Mean Maximum.	Mean Minimum.	e_1.	Approx. date of Minimum.	A_2.	e_2.
ENGLAND.								
Sunderland . . .	8·83	4·61	13·12	3·90	251°	Feb. 3	·52	40
Scarborough . .	9·21	4·95	14·16	4·26	252°	,, 2	·48	11
Spurn . . .	9·29	5·34	14·63	3·95	246°	,, 8	·39	25
Outer Dowsing . .	9·37	4·66	14·03	4·71	234°	,, 20	·47	27
Leman and Ower .	9·40	5·39	14·79	4·01	237°	,, 17	·35	35
Newarp . . .	9·67	5·56	15·23	4·11	237	,, 17	·57	18
Shipwash . . .	11·00	6·05	17·05	4·95	235°	,, 19	72	63
E. Goodwin . .	11·12	4·60	16·00	6·80	249°	,, 5	·31	24
Varne* . . .	11·34	4·84	16·18	6·50	247°	,, 7	·24	—
Royal Sovereign .	11·12	5·39	16·51	5·73	235°	,, 19	·25	24
Owers . . .	11·18	5·34	16·52	5·84	235°	,, 19	·37	41
Shambles . . .	11·23	4·67	15·90	6·56	229°	,, 25	·29	20
Salcombe . . .	11·18	4·17	15·35	7·01	241°	,, 13	·48	27
Falmouth . . .	11·68	3·45	15·13	8·23	236°	,, 18	·31	7
Scilly	12·18	3·45	15·63	8·73	247°	,, 7	·33	84
Seven Stones . .	12·07	3·11	15·18	8·96	231°	,, 23	·56	65
Newquay . . .	11·62	4·78	16·40	6·84	251°	,, 3	·23	50
Padstow . . .	11·56	4·67	16·23	6·89	249°	,, 5	·61	47
Newquay and Padstow	11·56	4·73	16·29	6·83	250°	,, 4	·40	47
English and Welsh Grounds . . .	10·62	6·56	17·18	4·06	250°	,, 4	·47	46
Helwick . . .	10·79	5·28	16·07	5·51	237°	,, 17	·30	13
Helwick (mean) . .	10·84	5·28	16·12	5·56	234°	,, 20	·42	40
St. Ann's Head, Pembroke . . .	11·00	3·84	15·29	7·61	235°	,, 20	·20	66
Cardigan Bay . .	10·62	3·67	14·29	6·95	228°	,, 26	·26	5
Carnarvon Bay . .	10·51	3·78	14·29	6·73	225°	Mar. 3	·27	6
Holyhead, Old Pier .	10·40	4·78	15·18	5·62	241°	Feb. 13	·21	39
N.W.L.V. Liverpool B.	10·06	5·39	15·45	4·67	240	,, 14	·55	34
Bahama Bank . .	9·73	4·45	14·18	5·28	235°	,, 19	·34	16°
Solway . . .	9·45	6·12	15·57	3·33	255°	Jan. 30	·14	74
SCOTLAND.								
Ballantrae . . .	9·48	4·34	13·82	5·14	249°	Feb. 5	·46	56
Lamlash, Arran . .	9·63	3·93	13·56	5·70	247°	,, 7	·50	73
Ailsa Craig** . .	9·83	3·73	13·56	6·10	233°	,, 21	·49	86
Oban	9·61	3·32	12·93	6·29	229°	,, 25	·48	47
Bernera . . .	9·46	3·28	12·74	6·18	239°	,, 15	·61	86
Harris . . .	9·38	3·35	12·73	6·03	237°	,, 17	·48	72
Harris and Bernera .	9·42	3·31	12·73	6·11	238°	,, 16	·54	81
Stornoway . . .	9·33	4·99	14·32	4·34	260°	Jan. 25	·58	68
Stornoway . . .	9·40	4·14	13·54	5·26	250°	Feb. 4	·48	57
Lerwick . . .	8·40	3·33	11·73	5·07	244°	,, 10	·44	57
Kirkwall . . .	8·36	4·05	12·41	4·31	251°	,, 3	·32	52
Wick	8·85	3·33	12·18	5·52	239°	,, 15	·22	46
Cromarty . . .	8·42	5·08	13·50	3·34	254°	Jan. 31	·57	87
Fraserburgh . .	8·11	4·41	12·24	3·42	247°	Feb. 7	·74	43
Pennant . . .	8·38	4·65	13·03	3·73	252°	,, 2	·37	44
Fraserburgh and Pennant . . .	8·28	4·56	12·84	3·72	250°	,, 4	·51	42

TABLE II.—HARMONIC CONSTANTS OF MEAN SURFACE TEMPERATURES AT BRITISH COASTAL STATIONS—*continued.*

	A 0.	A 1.	Mean Maximum.	Mean Minimum.	e 1.	Approx. date of Minimum.	A 2.	e 2.
SCOTLAND—*continued.*								
Rattray Head** . .	8·53	3·94	12·47	4·59	237°	Feb 17	·32	70°
Peterhead . . .	8·53	4·18	12·71	4·35	235°	„ 19	·39	41°
Aberdeen, Cove Bay .	8·42	3·53	11·95	4·89	236°	„ 18	·42	53°
Usan, Montrose . .	8·53	4·23	12·76	4·30	249°	„ 5	·44	28°
Abertay, L.V. . .	8·40	4·88	13·28	3·52	245°	„ 9	·39	72°
„ „ **. .	8·69	4·32	13·01	4·37	238°	„ 16	·30	50°
North Carr** . .	8·79	4·01	12·80	4·78	234°	„ 20	·31	74°
Burntisland . .	8·58	4·58	13·16	4·00	248°	„ 6	·32	62°
Dunbar . . .	8·91	4·47	13·38	4·44	244°	„ 10	·27	61°
Burnmouth . .	8·80	4·29	13·09	4·51	243°	„ 11	·31	57°
IRELAND.								
Kish Bank . . .	9·98	3·89	13·87	6·09	237°	Feb. 17	·32	86°
Coningbeg . . .	10·72	3·39	14·11	7·33	229°	„ 25	·21	142°
Daunt's Rock . .	10·84	3·38	14·22	7·46	241°	„ 13	·20	61°
Castletownshend .	11·06	3·19	14·25	7·87	255°	Jan. 30	·46	130°
Minard, Dingle Bay .	11·06	4·57	15·63	6·49	260°	„ 25	·51	75°
Seafield . . .	11·00	4·79	15·79	6·21	263°	„ 22	·38	99°
Liscannor . . .	11·02	4·43	15·45	6·59	258°	„ 27	·57	36°
Arran, N. Island .	11·07	4·72	15·79	6·35	256°	„ 29	·35	59°
Cleggan . . .	10·59	3·96	14·55	6·63	254°	„ 31	·34	52°
Blacksod Point . .	10·74	5·12	15·86	5·62	265°	„ 20	·34	78°
Cleggan . . .	10·68	5·32	16·00	5·36	260°	„ 25	·35	82°
Ballyglass . . .	10·62	4·16	14·78	6·46	256°	„ 29	·41	49°
Killybegs . . .	10·54	5·38	15·92	5·16	260°	„ 25	·53	41°
Dunfanaghy . .	9·97	4·37	14·34	5·60	251°	Feb. 3	·38	61°
Portrush . . .	9·47	4·37	13·84	5·10	250°	„ 4	·47	38°
Cushendall . .	10·63	3·40	14·03	7·23	225°	Mar. 1	·36	346°
Teclin . . .	10·12	4·58	14·70	5·54	259°	Jan. 26	·39	61°
Donaghadee . .	10·62	3·27	13·89	7·35	233°	Feb. 21	·51	53°
South Rock . .	10·28	3·09	13·37	7·19	220°	Mar. 6	·04	344°

TABLE III.—North Sea Temperature Observations from Captains of Liners.

Leith to London, 1904–13.

	Jan	Feb.	March.	April.	May.	June.	July.	August.	Sept.	Oct.	Nov.	Dec.	Mean.
Bass Rock . . .	5·40	4·73	5·00	5·97	7·93	10·49	12·48	12·79	12·05	10·81	8·53	6·77	8·58
St. Abbs . . .	5·68	4·94	5·05	5·92	7·73	10·28	12·41	12·75	12·00	10·76	8·72	7·01	8·60
Farns . . .	5·85	5·14	5·18	5·98	7·62	10·13	12·28	12·69	11·89	10·81	8·81	7·27	8·64
Coquet . . .	6·09	5·30	5·19	5·98	7·77	10·53	12·16	12·86	11·99	11·00	9·05	7·37	8·77
Tyne . . .	6·23	5·48	5·37	6·15	8·09	10·90	12·78	13·23	12·24	11·11	9·04	7·43	9·00
Whitby . . .	5·80	5·32	5·41	6·21	8·23	10·80	13·05	13·34	12·59	11·49	9·03	7·31	9·05
Flamboro' . .	5·26	4·76	5·15	6·36	8·45	11·04	13·06	13·58	13·17	11·84	8·93	6·95	9·05
Spurn . . .	5·71	5·03	5·21	6·43	8·38	10·85	12·73	13·82	13·31	12·32	9·33	7·15	9·19
Dudgeon . . .	5·14	4·64	5·07	6·58	8·99	11·73	13·38	14·60	13·78	12·55	9·43	6·86	9·39
Cromer . . .	4·79	4·41	4·84	6·72	9·26	12·32	14·47	15·43	14·40	12·71	9·23	6·79	9·61
Lowestoft . .	4·52	4·18	4·80	6·83	9·70	13·02	15·48	16·22	14·93	12·94	9·09	6·57	9·86
Orford Ness . .	4·77	4·30	4·93	6·94	9·67	12·99	15·76	16·60	15·39	13·42	9·38	6·89	10·09

Leith to Hamburg, 1904–13.

	Jan	Feb.	March.	April.	May.	June.	July.	August.	Sept.	Oct.	Nov.	Dec.	Mean.
2° W. . . .	6·37	5·34	5·22	5·91	7·93	10·51	12·45	13·19	12·19	11·07	9·28	7·63	8·92
1° W. . . .	6·74	5·76	5·46	6·01	7·84	10·66	12·97	13·75	12·52	11·11	9·32	7·98	9·18
0°	6·73	5·92	5·60	6·10	7·95	10·93	13·50	14·31	13·04	11·35	9·22	7·97	9·38
1° E. . . .	6·51	5·77	5·56	6·10	8·10	11·12	13·79	14·51	13·28	11·58	9·09	7·77	9·43
2° E. . . .	6·10	5·34	5·22	6·10	8·33	11·43	14·04	14·68	13·56	12·09	9·39	7·48	9·48
3° E. . . .	5·70	4·89	4·92	5·96	8·55	11·82	14·17	14·95	14·04	12·51	9·86	7·41	9·59
4° E. . . .	5·74	4·79	4·72	5·76	8·56	12·02	14·72	15·23	14·48	12·87	10·38	7·94	9·77
5° E. . . .	6·03	4·92	4·64	5·68	8·70	12·18	14·80	15·49	14·96	13·41	10·86	8·33	10·00
6° E. . . .	5·72	4·61	4·43	5·68	8·86	12·42	15·09	15·92	15·38	13·65	10·73	8·15	10·05
7° E. . . .	5·00	3·86	4·02	5·68	8·89	12·66	15·38	16·24	15·48	13·47	10·25	7·51	9·87

TABLE III.—North Sea Temperature Observations from Captains of Liners—*continued.*

	Jan.	Feb.	March.	April.	May.	June.	July.	August.	Sept.	Oct.	Nov.	Dec.	Mean.
Leith to Christiansand, 1904–13.													
1° W.	6·22	5·49	5·23	5·67	7·57	10·37	12·70	12·92	11·92	10·93	9·62	8·31	8·91
0°	6·50	5·68	5·46	6·18	7·92	10·93	13·18	13·60	12·28	11·00	9·42	8·35	9·21
1° E.	6·91	5·89	5·49	6·13	7·98	10·99	13·59	14·05	12·71	11·02	9·23	8·19	9·35
2° E.	6·52	5·64	5·40	6·11	7·99	11·09	14·02	14·40	13·10	11·23	8·91	7·79	9·35
3° E.	6·03	5·27	5·13	5·85	7·87	11·17	13·95	14·32	13·13	11·12	8·84	7·53	9·18
4° E.	5·75	4·92	4·88	5·59	7·75	11·29	14·01	14·36	13·05	11·01	8·58	7·42	9·05
5° E.	5·56	4·82	4·70	5·47	7·74	11·20	13·87	14·19	12·97	10·88	8·61	7·44	8·96
6° E.	5·21	4·20	4·45	5·22	8·01	11·63	13·94	14·60	13·11	10·95	8·26	7·37	8·91
Newcastle to Bergen, 1906–13.													
1° W.	6·75	5·74	5·58	5·90	8·25	10·59	12·74	13·75	12·50	10·96	9·39	7·75	9·15
0°	6·81	5·92	5·63	6·06	8·12	10·71	12·74	13·85	12·73	11·14	9·30	7·93	9·24
1° E.	6·85	6·00	5·65	6·13	8·07	10·63	12·74	13·89	12·84	11·24	9·12	7·90	9·25
2° E.	6·69	5·98	5·63	6·10	8·14	10·63	13·02	14·11	13·06	11·35	8·85	7·60	9·26
3° E.	6·37	5·71	5·47	6·00	8·11	10·76	13·31	14·05	12·96	11·14	8·80	7·39	9·17
4° E.	6·24	5·42	5·36	5·76	8·13	10·93	13·33	14·07	12·97	11·05	8·88	7·37	9·13
5° E.	5·49	5·18	4·93	5·20	9·25	11·12	13·41	14·62	13·35	10·92	8·75	7·17	9·12
Harwich to Hamburg, 1904–13.													
2° E.	5·81	4·91	5·75	6·59	8·95	11·95	14·51	15·76	15·43	13·48	10·22	7·79	10·10
3° E.	5·97	5·24	5·82	6·65	9·05	11·90	14·34	15·78	15·10	13·30	10·67	8·14	10·16
4° E.	5·74	4·92	5·48	6·97	9·62	12·80	15·21	16·19	15·23	13·19	10·25	7·74	10·28
5° E.	4·91	4·27	5·13	7·12	10·18	13·68	16·13	16·67	15·53	13·04	9·77	6·98	10·29
6° E.	4·44	3·92	4·87	6·62	10·05	13·48	16·20	16·72	15·53	12·95	9·38	6·74	10·08
7° E.	4·02	3·29	4·30	6·05	9·59	13·29	15·79	16·12	15·46	12·71	8·86	6·30	9·65

TABLE IV.—Harmonic Constants from North Sea Observations.

Leith to London, 1904–13.

	A_0.	A_1.	Mean Maximum.	Mean Minimum.	e_1.	A_2.	e_2.
Bass Rock, 1904–13 .	8·58	4·10	12·68	4·48	236°	·32	67°
St. Abbs, 1904–13 .	8·60	3·97	12·57	4·63	234°	·39	68°
Farn, 1904–13 . .	8·64	3·83	12·47	4·81	232°	·40	67°
Coquet, 1906–13 . .	8·77	3·84	12·61	4·93	232°	·40	77°
Tyne, 1906–13 . .	9·00	3·95	12·95	5·05	234°	·50	76°
Whitby, 1906–13 .	9·05	4·17	12·22	4·88	235°	·37	60°
Flamborough, 1904–13	9·05	4·56	13·61	4·49	236°	·20	21°
Spurn	9·19	4·48	13·67	4·71	233°	·24	0°
Dudgeon, 1906–13 .	9·40	5·01	14·41	4·39	237°	·16	20°
Cromer, 1904–13 .	9·61	5.57	15·18	4·04	240°	·22	19°
Lowestoft, 1904–13 .	9·86	6·10	15·90	3·76	242°	·30	33°
Orford Ness, 1904–13 .	10·09	6·19	16·28	3·90	240°	·36	24°
Leith to Hamburg, 1904–13.							
2° W.	8·92	3·91	12·83	5·01	230°	·48	80°
1° W.	9·18	3·95	13·13	5·23	230°	·73	70°
0°	9·38	4·17	13·55	5·21	232°	·85	61°
1° E.	9·43	4·39	13·82	5·04	233°	·83	58°
2° E.	9·48	4·77	14·25	4·71	234°	·61	59°
3° E.	9·59	5·20	14·79	4·39	234°	·45	69°
4° E.	9·77	5·44	15·21	4·33	232°	·46	84°
5° E.	10·00	5·58	15·58	4·42	229°	·44	91°
6° E.	10·05	5·92	15·97	4·03	230°	·39	86°
7° E.	9·87	6·34	16·21	3·53	234°	·34	83°
Leith to Christiansand, 1904–13.							
1° W.	8·91	3·84	12·75	5·07	228°	·61	95°
0°	9·21	3·92	13·13	5·29	231°	·70	85°
1° E.	9·35	4·16	13·51	5·19	232°	·90	74°
2° E.	9·35	4·37	13·72	4·98	234°	·91	64°
3° E.	9·18	4·57	13·75	4·61	235°	·85	60°
4° E.	9·05	4·73	13·78	4·32	236°	·75	67°
5° E.	8·96	4·73	13·69	4·23	235°	·85	74°
6° E.	8·91	5·05	13·96	3·86	237°	·79	78°

TABLE IV.—Harmonic Constants from North Sea Observations—*continued.*

Leith to Stavanger, 1904–13.

	A 0.	A 1.	Mean Maximum.	Mean Minimum.	e 1.	A 2.	e 2.
2° W.	8·73	3·73	12·46	5·00	221°	·43	—
1° W.	9·10	3·50	12·60	5·60	224°	·65	—
0°	9·44	3·58	13·02	5·86	227°	·84	—
1° E.	9·39	3·66	13·05	5·73	229°	·91	—
2° E.	9·42	3·76	13·18	5·66	230°	1·07	—
3° E.	9·22	3·94	13·16	5·28	232°	1·07	—
4° E.	9·09	4·27	13·36	4·82	233°	1·05	—
5° E.	8·76	5·09	13·85	3·67	228°	1·03	—

Newcastle to Bergen, 1906–13.

	A 0.	A 1.	Mean Maximum.	Mean Minimum.	e 1.	A 2.	e 2.
1° W.	9·16	3·89	13·05	5·27	231°	·65	69°
0°	9·24	3·90	13·14	5·34	231°	·68	64°
1° E.	9·25	3·91	13·16	5·34	231°	·71	58°
2° E.	9·26	4·06	13·32	5·20	233°	·79	50°
3° E.	9·17	4·19	13·36	4·98	234°	·78	55°
4° E.	9·13	4·32	13·45	4·81	234°	·76	62°
5° E.	9·12	4·73	13·85	4·39	237°	·67	67°

Harwich to Hamburg, 1904–13.

	A 0.	A 1.	Mean Maximum.	Mean Minimum.	e 1.	A 2.	e 2.
2° E.	10·10	5·43	15·53	4·67	232°	·42	6°
3° E.	10·16	5·23	15·39	4·93	232°	·34	17°
4°	10·28	5·60	15·88	4·68	237°	·30	47°
5° E.	10·28	6·25	16·53	4·03	242°	·27	58°
6° E.	10·08	6·47	16·55	3·61	242°	·34	53°
7° E.	9·65	6·59	16·24	3·06	241°	·28	56°

Leith to Rotterdam, 1911–12.

	A 0.	A 1.	Mean Maximum.	Mean Minimum.	e 1.	A 2.	e 2.
2° W.	9·01	3·88	12·89	5·13	236°	·55	—
1° W.	9·26	3·82	13·08	5·44	235°	·72	—
0°	9·50	4·19	13·69	5·31	238°	·69	—
1° E.	9·58	4·36	13·94	4·62	234°	·63	—
2° E.	9·90	5·23	15·13	4·67	237°	·78	—
3° E.	10·61	5·23	15·84	5·38	231°	·74	—
4° E.	10·65	6·63	17·28	4·02	245°	·85	—

TABLE V.—English Channel Observations (1904–13).

(From Data furnished by the Board of Agriculture and Fisheries.—Mr. E. C. Jee.)

(*a*) Plymouth to Gulf of St. Malo.

N.	W.	Jan.	Feb.	March.	April.	May.	June.	July.	August.	Sept.	Oct.	Nov.	Dec.	Mean.
50° 08′	3° 49′	9·80	8·59	8·46	9·16	10·63	12·46	14·13	15·22	14·85	14·33	12·52	11·03	11·77
49° 52′	3° 15′	10·02	8·96	8·84	9·62	10·86	12·55	14·16	15·12	14·78	14·35	12·72	11·31	11·94
49° 43′	2° 55′	9·86	8·75	8·72	9·56	10·69	12·55	14·02	15·16	15·03	14·56	12·84	11·42	11·93
49° 31′	2° 30′	9·74	8·74	8·58	9·63	10·77	12·80	14·19	15·45	15·54	14·95	13·07	11·30	12·06
49° 19′	2° 25′	9·34	8·37	8·53	9·54	11·22	13·60	15·30	16·50	16·13	14·93	13·07	10·98	12·29
48° 53′	2° 25′	9·30	8·28	8·02	9·07	10·61	13·01	14·97	16·31	16·17	15·08	12·80	10·91	12·04

(*b*) Southampton to St. Malo.

N.	W.	Jan.	Feb.	March.	April.	May.	June.	July.	August.	Sept.	Oct.	Nov.	Dec.	Mean.
50° 27′	1° 42′	8·55	7·45	7·20	8·15	10·05	12·50	14·70	15·80	15·55	14·45	12·15	9·90	11·37
50° 22′	1° 45′	8·95	7·85	7·50	8·20	10·05	12·20	14·30	15·40	15·40	14·45	12·30	10·10	11·39
50° 13′	1° 49′	9·40	8·35	7·85	8·40	10·05	12·00	13·95	15·05	15·25	14·55	12·55	10·60	11·50
50° 4′	1° 55′	9·60	8·45	8·00	8·45	10·15	12·00	13·90	15·00	15·25	14·55	12·60	10·75	11·56
49° 55′	1° 59′	9·70	8·55	8·10	8·55	10·25	12·10	13·90	15·15	15·35	14·55	12·75	10·80	11·65
49° 42′	2° 1′	9·30	8·10	7·90	8·55	10·40	12·25	14·35	15·60	15·65	14·75	12·45	10·35	11·61

(*c*) Southampton to Havre.

N.	W.	Jan.	Feb.	March.	April.	May.	June.	July.	August.	Sept.	Oct.	Nov.	Dec.	Mean.
50° 36′	0° 45′	7·53	6·76	6·82	7·86	10·23	13·10	15·47	16·49	15·82	14·21	11·52	9·21	11·25
50° 25′	0° 37′	8·71	7·76	7·37	8·10	9·73	12·11	14·20	15·38	15·59	14·63	12·13	10·12	11·32
50° 14′	0° 29′	8·94	8·15	7·87	8·30	9·87	11·95	13·86	15·11	15·46	14·56	12·39	10·58	11·42
50° 3′	0° 20½′	8·87	7·99	7·83	8·25	9·90	11·97	13·99	15·21	15·61	14·71	12·35	10·57	11·44
49° 52½′	0° 12½′	8·22	7·49	7·56	8·26	10·16	12·46	14·55	15·72	15·88	14·76	12·18	10·05	11·44
49° 41½′	0° 4′	7·46	6·84	7·33	8·29	10·56	13·12	15·25	16·23	16·15	14·62	12·69	9·40	11·50

TABLE VI.—English Channel Observations.
Harmonic Constants.

Plymouth to St. Malo.

N.	W.	A 0.	A 1.	Mean Maximum.	Mean Minimum.	e 1.	Approximate Date of Minimum.	A 2.
50° 08′	3° 49′	11·77	3·26	15·03	8·51	216°	Mar. 10	·16
49° 52′	3° 15′	11·94	3·13	15·07	8·81	220°	„ 6	·10
49° 43′	2° 55′	11·93	3·28	15·21	8·65	216°	„ 10	·02
49° 31′	2° 30′	12·06	3·51	15·57	8·55	217°	„ 9	·08
49° 19′	2° 25′	12·29	4·06	16·35	8·23	231°	Feb. 23	·12
48° 53′	2° 25′	12·04	4·19	16·23	7·85	224°	Mar. 2	·22
Southampton to St. Malo.								
50° 27′	1° 42′	11·37	4·34	15·71	7·03	226°	Feb. 28	·26
50° 22′	1° 45′	11·39	4·03	15·42	7·36	220°	Mar. 6	·22
50° 13′	1° 49′	11·50	3·72	15·22	7·78	213°	„ 13	·22
50° 04′	1° 55′	11·56	3·64	15·20	7·92	212°	„ 14	·22
49° 55′	1° 59′	11·65	3·61	15·36	8·04	212°	„ 14	·22
49° 42′	2° 01′	11·64	3·97	15·61	7·67	220°	„ 6	·30
Southampton to Havre.								
50° 36′	0° 45′	11·25	4·97	16·22	6·28	239°	Feb. 15	·33
50° 25′	0° 37′	11·32	4·16	15·48	7·16	219°	Mar. 7	·3
50° 14′	0° 29′	11·42	3·84	15·26	7·58	214°	„ 12	·3
50° 03′	0° 20½′	11·44	3·96	15·40	7·48	215°	„ 11	·3
49° 52½′	0° 12½′	11·44	4·38	15·82	7·06	226°	Feb. 28	·3
49° 41½′	0° 04′	11·50	4·88	16·38	6·62	235°	„ 19	·16

TABLE VII.—MEAN SEA TEMPERATURE FROM CONTINENTAL STATIONS.

	Latitude.	Longitude.	Period.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Mean.
Noord-Hinder . .	51° 35′	2° 37′	1884–1908	6·8	5·7	5·8	7·4	9·9	13·0	15·7	17·0	16·5	14·4	11·6	8·8	11·0
Schouwenbank . .	51° 47′	3° 27′	1882–1906	4·6	4·2	4·8	7·3	10·5	14·0	16·9	17·9	16·9	13·7	10·1	6·7	10·7
Maas	52° 1′	3° 54′	1891–1910	4·3	3·8	4·7	7·0	10·2	13·7	16·4	17·5	16·3	13·6	9·9	6·6	10·3
Haaks . . .	52° 58′	4° 18′	1890–1909	5·4	4·6	4·8	6·7	9·7	13·0	15·6	16·8	16·2	13·9	10·8	7·7	10·5
Terschellingerbank .	53° 27′	4° 52′	1886–1908	4·8	4·1	4·3	6·4	9·6	13·2	15·8	16·9	16·1	13·5	10·2	7·1	10·2
Heligoland . .	—	—	1893–1907	3·91	2·64	3·12	5·18	8·50	12·27	15·00	16·21	15·56	13·19	9·90	6·48	9·36
Horn Reef . .	—	—	1900–1913	4·16	2·78	3·28	5·02	8·66	12·23	14·84	15·64	15·00	13·12	9·87	7·18	9·31
The Skaw . . .	—	—	1900–1913	3·42	2·36	2·58	4·96	9·12	13·59	16·08	16·09	14·14	11·52	8·09	5·70	8·97
Torungen . . .	58° 25′	8° 48′	1874–1903	2·3	1·4	1·3	3·7	8·3	12·7	15·4	15·7	13·8	10·5	7·1	4·3	8·0
Utsire . . .	59° 18′	4° 53′	,,	5·1	4·2	4·0	5·3	8·1	11·5	14·0	14·7	13·4	11·0	8·4	6·5	8·9
Hellisö . . .	60° 45′	4° 43′	,,	5·5	4·7	4·4	5·0	7·1	10·2	12·3	13·1	12·8	10·8	8·7	6·8	8·5
Ona	62° 52′	6° 33′	,,	4·9	4·4	4·2	5·2	7·1	9·5	4·7	12·6	12·2	10·4	8·1	6·1	8·0
Prestö . . .	64° 47′	11° 7′	,,	2·9	2·0	2·5	4·4	7·4	10·6	12·3	12·4	10·5	7·8	5·4	3·4	6·8
Nordöerne . . .	64° 48′	10° 33′	,,	4·2	3·5	3·2	4·1	6·3	9·4	12·2	12·2	10·7	8·7	6·7	4·9	7·2
Andenes . . .	69° 20′	16° 8′	,,	1·5	0·7	0·9	2·4	5·0	8·4	10·3	10·6	8·3	5·5	3·6	2·2	5·0
Gjesvor . . .	71° 06′	25° 22′	,,	1·3	0·8	0·7	1·8	3·7	6·2	8·2	8·5	7·1	5·0	3·1	1·6	4·0

NOTE.—The Dutch data supplied by the late Professor Wind; the Norwegian data from Mr. Aksel S. Steen, of the Meteorological Institute of Christiania; the Danish data from the Danish Meteorological Year-book; and the data for Heligoland from A. C. Reichard, *Wissensch. Meeresuntersuchungen*, Heligoland, Bd. x., 1909.

TABLE VIII.—MEAN SEA TEMPERATURE AT CONTINENTAL STATIONS. HARMONIC CONSTANTS.

	A 0.	A. 1.	Mean Maximum.	Mean Minimum.	e 1.	Approximate Date of Minimum.	A 2.	e 2.
Noord-Hinder .	11·0	5·71	16·71	5·29	232°	Feb. 22	·30	36°
Schouwenbank .	10·6	6·95	17·55	3·65	242°	„ 12	·39	19°
Maas . . .	10·3	6·85	17·15	3·45	241°	„ 13	·28	12°
Haaks . . .	10·5	6·22	16·62	4·18	235°	„ 19	·21	39°
Terschellingerbank	10·2	6·44	16·64	3·76	238°	„ 16	·28	48°
Heligoland . .	9·36	6·83	16·19	2·53	234°	„ 20	·14	69°
Horn Reef . .	9·31	6·51	15·82	2·80	233°	„ 21	·29	52°
The Skaw . .	8·97	6·87	15·84	2·10	239°	„ 15	·88	65°
Torungen . .	8·06	7·36	15·42	0·70	243°	„ 11	·88	92°
Utsire . . .	8·95	5·29	14·24	3·66	238°	„ 16	·76	70°
Hellisö . . .	8·45	4·72	13·17	3·73	230°	„ 24	·58	56°
Ona . . .	8·03	4·25	12·28	3·78	233°	„ 21	·45	33°
Prestö . . .	6·8	5·1	11·9	1·7	250°	„ 4	·60	77°
Nordöerne . .	7·18	4·45	11·63	2·73	239°	„ 15	·92	69°
Andenes . .	5·0	4·8	9·8	0·2	249°	„ 5	1·0	79°
Gjesvor . .	3·9	3·0	6·9	0·9	245°	„ 9	·80	61°

TABLE IX.—North Atlantic Temperatures. Annual Means (Centigrade).

(Compiled from Charts in the Danish Meteorological Year-book, 1903–13.)

	25°					20°					15°					10°					5°				0°
64–65	6·2	6·4	6·5	6·4	—	—	—	—	—	6·3	5·1	4·0	5·1	6·1	5·9	5·3	—	—	—	—	—	—	—	—	—
63–64	—	—	7·1	7·3	7·5	7·8	7·8	7·9	7·6	7·6	8·5	7·3	7·0	6·8	7·0	7·3	7·6	7·0	7·1	—	—	—	—	—	—
62–63	—	—	—	—	—	8·6	8·3	8·4	8·5	8·6	8·7	8·6	8·5	8·5	8·4	8·2	8·0	7·8	7·6	8·3	—	—	—	—	—
61–62	—	—	—	—	—	—	—	9·5	9·0	8·9	8·8	8·9	9·0	9·0	9·0	8·7	8·8	8·1	7·8	8·4	8·6	8·5	8·8	9·3	—
60–61	—	—	—	—	—	9·5	9·7	9·6	9·5	9·6	9·6	9·5	9·3	9·3	9·1	9·1	9·1	9·2	8·9	9·0	9·1	9·3	9·3	9·1	9·3
59–60	—	—	—	—	—	9·2	9·2	9·1	9·4	9·5	9·6	9·6	9·5	9·7	9·6	9·6	9·6	9·5	9·7	9·6	9·4	9·1	8·9	8·8	8·9

TABLE X.—North Atlantic Temperatures. Annual Means (Fahrenheit).
(Compiled from data in the possession of the Meteorological Office.)

Lat.N.	70° W.					60°					50°					40°				30
58–60	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
56–58	—	—	—	—	—	—	—	—	—	—	—	—	—	—	45·5	46·1	47·6	48·4	49·4	49·9
54–56	—	—	—	—	—	—	—	—	—	—	46·5	47·0	46·7	45·7	46·7	47·3	47·0	47·9	48·1	48·8
52–54	—	—	—	—	—	—	—	40·0	38·9	41·3	45·1	47·1	47·7	48·6	47·9	48·7	48·4	48·2	49·0	49·5
50–52	—	—	—	—	—	45·0	42·7	40·1	41·2	42·2	46·0	48·4	50·6	51·5	51·5	51·2	51·8	52·4	53·1	53·7
48–50	42·9	44·3	43·2	44·3	43·1	47·0	46·0	47·0	42·2	41·8	40·5	43·7	45·7	50·4	55·2	55·7	55·6	55·6	55·7	55·7
46–48	—	—	—	—	43·9	45·1	43·5	43·3	41·7	41·5	40·8	42·1	45·6	50·6	56·7	57·8	58·1	58·3	58·1	58·1
44–46	—	41·4	36·4	44·8	44·7	44·2	45·1	45·2	45·3	44·5	43·0	47·7	54·6	59·6	60·4	60·4	60·2	60·2	60·5	60·7
42–44	49·2	47·9	47·3	49·4	49·7	51·2	52·6	52·9	51·8	48·2	48·6	57·9	62·7	62·9	62·9	62·9	62·9	62·7	62·7	62·6
40–42	51·4	52·8	57·2	60·1	62·2	64·0	64·3	64·0	63·1	62·5	61·5	62·6	65·1	65·7	65·2	65·2	65·2	64·9	64·4	64·2
38–40	63·3	65·3	67·7	69·4	69·7	69·6	69·7	69·2	69·0	68·6	68·4	67·7	67·2	67·1	67·2	67·1	66·7	66·5	66·0	65·1
36–38	72·0	71·7	71·3	71·2	70·7	71·0	70·2	70·2	69·7	69·7	69·6	69·2	69·2	69·0	68·7	68·3	68·0	67·8	67·4	66·8
34–36	71·3	71·7	71·5	71·2	71·2	70·9	70·7	70·4	70·2	70·2	70·0	70·2	70·2	70·0	70·0	69·6	69·2	68·7	68·7	68·2
32–34	71·9	71·9	72·0	72·0	72·1	71·9	72·1	71·9	71·8	71·7	71·7	71·7	71·5	71·5	71·1	70·7	70·9	70·3	70·1	69·7
30–32	73·3	73·4	73·6	73·5	73·3	74·1	73·5	73·0	73·4	73·2	72·9	73·1	73·1	72·6	72·3	72·0	72·0	71·4	71·2	70·5
28–30	75·2	75·6	75·5	75·2	75·2	75·2	75·4	75·2	74·7	74·8	74·3	74·2	73·9	74·0	73·7	73·2	72·9	72·9	72·2	72·2

Lat.N.	30° W.					20°					10°				0
58–60	50·0	50·9	51·3	50·7	50·9	50·3	50·2	50·2	50·0	50·5	50·1	49·9	50·1	48·6	48·0
56–58	49·7	50·2	50·5	50·7	50·9	51·2	51·0	—	—	—	—	—	—	—	
54–56	49·4	50·3	51·2	51·7	52·2	52·1	52·2	52·2	51·9	52·1	51·7	51·2	50·6	49·7	48·2
52–54	50·2	51·6	52·2	52·7	53·0	53·4	53·6	53·8	53·4	53·3	—	—	51·4	51·2	—
50–52	53·9	54·2	54·3	54·6	54·7	55·1	54·9	54·7	54·6	54·1	53·3	53·6	53·5	53·3	52·8
48–50	56·1	56·2	56·2	56·2	56·4	56·6	56·2	56·0	56·2	55·8	55·0	55·0	54·5	53·7	53·1
46–48	58·5	58·2	58·0	58·1	58·1	57·9	57·7	57·6	57·5	57·2	56·9	56·9	56·2	—	—
44–46	60·5	60·0	59·9	59·6	59·4	59·1	59·0	58·7	58·7	58·6	58·2	57·8	—	—	—
42–44	62·0	62·1	61·7	61·2	60·8	60·7	60·2	60·4	60·1	59·8	59·0	—	—	—	—
40–42	63·6	63·2	63·2	62·8	62·2	62·1	62·1	61·8	61·7	61·1	60·2	—	—	—	—
38–40	64·9	64·4	64·1	64·0	63·7	63·4	63·1	63·2	63·0	62·4	61·1	—	—	—	—
36–38	66·2	65·9	65·7	65·5	65·2	64·9	64·6	64·5	64·2	64·0	62·7	64·4	63·7	64·2	65·0
34–36	67·9	67·5	67·3	66·8	66·6	66·6	66·2	65·6	65·5	65·7	65·4	64·8	64·2	—	—
32–34	69·1	69·6	68·6	68·1	68·2	67·9	67·2	66·9	66·7	65·4	64·9	—	—	—	—
30–32	70·2	70·1	69·2	69·2	69·4	68·7	68·3	67·7	63·4	—	—	—	—	—	—
28–30	71·3	70·7	70·5	70·2	69·9	69·1	68·5	68·1	—	—	—	—	—	—	—

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ADDITIONAL NOTES ON THE DEEP CURRENTS OF THE NORTH SEA AS ASCERTAINED BY DRIFT BOTTLES.

By Captain C. H. BROWN,
Royal Technical College, Glasgow.

This Paper may be referred to as:
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ADDITIONAL NOTES ON THE DEEP CURRENTS OF THE NORTH SEA AS ASCERTAINED BY DRIFT BOTTLES.

By Captain C. H. BROWN.

In continuation of former Reports, I deal in this short paper with additional drift bottles from our earlier experiments, which have come to hand since the main results of these experiments were reported on; and also with a recent series of experiments, the success of which has been much interfered with by the exceptional conditions of the last year and a half.

In our first series of experiments, between June 1906 and September 1907—

1012 bottles were put away, and of this number
  200 were recovered up to January 1909, and these formed the basis of the First Report on the Deep Currents, published in the Fourth Report (Northern Area), 1906–1909.
  112 more bottles were recovered up to October 1913, the results being included in the Second Report on the subject (Fisheries Scotland Sci. Invest., 1913, II. (August 1914)). Since then another
  16 have been returned to us, making a total of 328.

These 16 additional bottles have been under water for periods ranging from 6 years 5 months to 8 years 3 months, while the distance between the positions of their departure and recovery only varies from 10 to 60 miles. The rate of drift of the sixteen is therefore very small, and so they add but little to the knowledge we have already gained from the other bottles of this series. The additional information they convey to us, on being incorporated in the previous statistics, does not appreciably change the direction or velocity of the currents as already determined and published.

The actual route followed by these dilatory messengers is obscure owing to the long time they have been adrift. They may have fouled something on the bottom, and so got held up on the way; some may have been drifting to and fro, or even carried round in a complete circle. A record of these additional bottles is herewith attached.

Second Experiment.—There were 787 bottles in this series, numbered consecutively from 100A to 387A and from 1100 to 1598, and all of them were put away at intervals between August 1909 and July 1911. Two hundred and four of them were recovered up to October 1913, and the information derived therefrom was discussed in the Second Report on the subject. The results indicated a slight modification,

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especially near the central areas, of the shape of the cyclonic system which was revealed by our former investigations. The experiment was of further value as it contributed independent confirmation of the general trend of the deep currents previously determined.

From October 1913 up to the present date, January 1916, only 27 more bottles of this series have been returned to us, 14 having been trawled up from the bottom, and 13 picked up on the beach.

It will be remembered that the bottles of this series were put away in lots of five at a time, so I have distinguished the cards of each lot by means of a reference number and the letters a, b, c, d, and e.

Of the 14 bottles trawled up, 9 of them (3c—5a—12c—14a—62e—63c—109a—112a—115b) have followed a direction which agrees with the curves as shown on the charts of the previous Reports, and 5 of them (40a—56c—61a—62c—125i) seem to have drifted for a short distance in a contrary direction. But all of them have been so long adrift, two to five years, and have covered, with one exception, such comparatively short distances, 5 to 320 miles, that the mean velocity attained by the 14 bottles, always assuming, as hitherto, that they have followed a straight line between their initial and terminal positions, works out at slightly less than 12 miles per year, a speed which does not sensibly modify our former results.

The exception to this slow progression was bottle 12c, which was put away to the westward of the Orkney Islands, and was picked up four years afterwards, 60 miles N.E. from Spurn Point, having apparently drifted round the north of the Orkneys, and down the east coast of Scotland for a distance of 322 miles, at an average speed of 25 miles per 100 days.

This is considerably above the average speed on this route, so much so that one might infer that the bottle had drifted on the surface, yet it was trawled up in 21 fathoms of water.

The remaining 13 bottles of this series were picked up on the beach, eleven of them on the Norwegian coast, all of which appear to have traversed much the same track as was apparently followed by others that have been carried to foreign coasts ; and two were found on the Shetland Islands.

One of these Shetland drifts, 40c, is of considerable value, as it appears to me to indicate that the system of deep currents forms a closed curve. This bottle was carried from the south edge of the Witch Ground to Sandwick Bay which is close to Sumburgh Head. This distance in a straight line measures 120 miles, but the direction of drift is diametrically opposite to that which has been firmly established. But it is easy to reconcile this apparently retrogressive movement with the curves on Chart III. of last Report. A reference to the chart attached hereto shows that the centre of the cyclonic system lies approximately over the Witch Ground, and it is highly probable that the bottle may at first have been carried a little to the eastward, then up the east side of the Witch Ground in a northerly direction, and finally to the westward into Sandwick Bay. Two hundred and fifty miles would be a generous distance to allow for this circular route, and as the bottle was 4 years 3 months on the journey, its average speed would be about 16 miles per 100 days, which compares favourably with the speeds already determined.

In support of this conjecture it might be as well to examine for

a moment the trawled bottles, 61a, 62c, and 125, which have, as already mentioned, followed a direction contrary to our previous knowledge.

It is quite conceivable that 61a, which was put away in area 67, instead of being carried to the N.W. towards the position where it was found, may also, like 40c, have been carried eastward across the Witch Ground, then northerly up the east side of it, and thence westerly into area 48 where it was trawled up. If such were the case, 180 miles would cover the distance on this assumed route, the average speed working out at about 18 miles per 100 days.

Group 125 was put away from the same position as group 61, but six months later, and one of this lot was also trawled up to the north and west of the initial position, and seems also to have been carried in opposition to the usual trend of the current. But the same argument as we have just applied to 61a could also be applied to this bottle, and if it has drifted round in the same way its mean velocity would be about 24 miles per 100 days.

Group 62 was a lot of 5 bottles put away in area 66. One was picked up 33 miles S. 48° E. from the original position, and so agrees with the former resultant, but the other bottle was carried 40 miles almost true north, which is considerably at variance with the mean direction for this area.

Presumably both of these bottles have in the first instance been carried in a south-easterly direction, and while the former may have been held up by some obstruction, the latter may have come under the influence of the north-going stream which eddies counter clockwise round the Witch Ground. If such be the case, then, it has travelled some 240 miles to reach the position where it was trawled up, at a speed of about 11 miles per 100 days.

The mean velocity attained by these four messengers is about 17 miles per 100 days. Although this is above the average speed of the south-going current, on the west side of the Witch Ground, yet it is a fair average for the north-going stream on the east side of it, and so far as their rate of progress is concerned, there seems no reason to doubt the probability of these bottles having followed a circular route. These assumed routes are shown in the accompanying chart.

We have not been able in our investigations of the bottom drift to prove that the deep currents eddy round and make a complete circle. There has already been an indication that this might be the case, derived, however, from the drift of a single bottle and referred to in the Second Report, page 5, but if the foregoing deductions regarding bottles 40c, 61a, 62c, and 125 be correct, then we are beginning to get indirect but cumulative evidence that at least the central eddies in the vicinity of the Witch Ground form a closed curve.

Little or no information has been got from the region lying to the east of the Shetland Islands, and it is in an endeavour to bridge this gap in our statistics that detailed reference has been made to these four bottles.

Third Experiment.—It was confidently expected that the results of the Third Experiment would yield valuable information and enable us to determine much that is obscure regarding the deep currents in the less frequented areas of the North Sea; also to furnish the material necessary to establish, if possible, a direct connection between those resultants which are widely separated.

With this object in view a greater number of bottles were put away than in the former experiments, especially in the northern waters, but the European War has interfered with the usual widely distributed operations of the fishing fleets, and hence there are very few returns to record.

At intervals between April 1914 and August 1914, 1890 bottles, numbered consecutively from 1B to 1890B, were put away from selected positions, but so far only 32 of the series have been recovered.

The observations are obviously too few in number on which to base an independent investigation and so enable us to amplify and to confirm or otherwise our previous work.

Six of the 32 bottles recovered were adrift for less than 30 days. These should be rejected owing to the unreliability of the speed deduced from them, due to the short time they have been under water, and to the excessive error thus caused in the average speed by even a slight inaccuracy in estimating the positions of their points of departure and recovery.

Sixteen agree fairly well in direction with our previous results. The remaining 10 have apparently been carried in an opposite direction, but most of these bottles have drifted for a comparatively short distance, and consequently do not have much influence on results. The two bottles of group 138 are interesting, inasmuch as they were put away at the same time and place, and picked up together 8 months later in the same sweep of a trawler's net.

The information revealed by the few bottles of this series that have come to hand is, on the whole, conflicting and contradictory, and I am inclined to think that in some cases the positions from which they were trawled up has not been given with the same degree of accuracy as in former days owing to the unusual difficulties of navigation caused by lack of guiding lights, &c.

CHAS. H. BROWN.

NOTE ON THE FOREGOING PAPER.

That the deep-water currents which course southward along the north-east coast of Scotland bend round again to the northward somewhere in the region of the Witch Ground, is a fact which has long been known, and has been duly depicted in Captain Brown's earlier charts of the bottom-currents of the North Sea. But the evidence furnished in this paper that these currents not only bend to the northward, but afterwards come round again in a complete cyclonic eddy, is welcome confirmation of an important and long-suspected hydrographical fact.

From the very beginning of our investigations, in 1902, it has been obvious that the hydrographical conditions in this region are remarkable and peculiar. Professor Helland-Hansen, in his report on our hydrographical investigations for that year,* called attention to the *cold* but highly saline water in this region, showed evidence from the distribution of salinity and temperature alone (deep-water current experiments being then lacking) of a slow cyclonic motion in the bottom layer, and stated that in all probability "there was an 'eddy' formed in the North Sea, similar to that formed in the central

* First Report [Cd. 2612] 1902–3 (1905), pp. 22, 23.

part of the channel between Shetland and the Faeroes," but that "there was not sufficient material available for a definite conclusion on this point." Again, Dr. A. J. Robertson, in his report on the work of 1907–8,* with the help of Captain Brown's earlier experiments, was able to show that the cold deep-water area tallied precisely with what these current-experiments suggested (if they did not yet completely prove), and that this deep, cold water formed the centre of a circular movement, itself remaining more or less in a state of rest. And (not to speak of many other references to the same phenomenon), my own charts of the salinity of the North Sea† showed that just in this region we have an area of minimal *variation* of salinity, the salinity here at the bottom varying less than ·1°/00 during the year. In short, all our information regarding this area now hangs well together, and the slow cyclonic eddy in the deep waters, with an all but stagnant "core," may be looked upon as a fact settled by observation and experiment.

* Fourth Report [4893], 1909, p. 149.
† Fourth Report, p. 89, etc.

D'Arcy W. Thompson.

TABLE I.—FIRST EXPERIMENT.—ADDITIONAL DRIFT BOTTLES RECOVERED BY TRAWLERS.

Reference No. of Card.	Position Cast out.	Position Recovered.	Depth of Water.	Date.		Period Adrift.	Distances between Position.	Direction, True.	Area.
				Cast out.	Recovered.				
			Fms.			y. m. d.	Miles.		
322	57° 59′ N.; 0° 57′ E.	57° 50′ N.; 1° 5′ E.	71	16/ 8/06	27/11/13	7 3 12	10	S. 26° E.	78
323	58° 28′ N.; 0° 20′ W.	58° 20′ N.; 1° 0′ W.	—	26/11/06	27/11/13	7 0 1	23	S. 69° W.	67
324	59° 32′ N.; 0° 0′	59° 25′ N.; 0° 25′ W.	79	20/ 6/06	8/ 1/14	7 6 19	14	S. 60° W.	40 and 49
325	59° 0′ N.; 0° 0′	59° 6′ N.; 0° 10′ E.	71	20/ 6/06	9/ 1/14	7 6 20	8	N. 41° E.	50
326	59° 6′ N.; 1° 0′ W.	58° 14′ N.; 0° 35′ W.	67	26/ 5/07	10/ 1/14	6 7 15	54	S. 14° E.	49, 58, 67
327	59° 43′ N.; 0° 7′ W.	59° 10′ N.; 0° 34′ W.	79	21/11/06	20/ 1/14	7 2 0	79	S. 35° W.	40 and 49
328	59° 45′ N.; 0° 35′ E.	59° 40′ N.; 0° 15′ E.	70	1/ 9/07	1/ 2/14	6 5 0	11	S. 64° W.	41
329	60° 34′ N.; 1° 15′ E.	60° 57′ N.; 1° 0′ E.	87	26/ 7/06	5/ 3/14	7 7 7	24	N. 18° W.	24
331	58° 25′ N.; 1° 40′ W.	57° 40′ N.; 1° 20′ W.	55	12/ 2/07	19/ 5/14	7 3 7	46	S. 13° E.	66, 76
333	58° 9′ N.; 1° 50′ W.	57° 14′ N.; 1° 22′ W.	65	12/ 2/07	7/ 7/14	7 4 25	57	S. 15° E.	66, 76, 86
334	56° 26′ N.; 1° 8′ W.	56° 14′ N.; 2° 0′ W.	24	20/12/06	28/ 2/15	8 2 8	31	S. 67° W.	108
336	58° 15′ N.; 1° 45′ W.	57° 40′ N.; 0° 30′ W.	61	12/ 6/06	17/ 4/15	8 10 5	53	S. 49° E.	66, 77

ADDITIONAL BOTTLES STRANDED ON THE COAST.

Reference No. of Card.	Position Cast out.	Position Recovered.	Depth of Water.	Cast out.	Recovered.	Period Adrift.	Distances between Position.	Direction, True.	Area.
335	60° 7′ N.; 1° 5′ W.	60° 20′ N.; 1° 50′ W. (Near Scalloway)	Beach.	21/11/06	7/ 3/15	8 3 15	60	—	—
332	59° 31′ N.; 0° 37′ E.	Marso	„	5/ 9/06	18/ 5/14	7 7 13	—	—	—
337	58° 0′ N.; 0° 45′ W.	62° 47′ N.; 24° 30′ E.	„	28/ 7/06	2/ 5/15	8 9 5	400	—	—
339	61° 25′ N.; 2° 50′ E.	64° 0′ N.; 9° 0′ E.	„	28/ 8/07	25/ 4/14	6 8 0	240	—	—

TABLE II.—SECOND EXPERIMENT.—ADDITIONAL DRIFT BOTTLES RECOVERED BY TRAWLERS.

Reference No. of Card.	Position Cast out.	Position Recovered.	Depth of Water.	Date. Cast out.	Date. Recovered.	Period Adrift. y.	m.	d.	Distances between Positions.	Drift in 100 Days.	Direction, True.	Area.
			Fms.			y.	m.	d.	Miles.			
3c	59° 10′ N.; 1° 27′ W.	57° 35′ N.; 1° 27′ W.	50	8/8/10	24/ 9/15	5	1	17	95	5	South.	48,57,66,76
5a	59° 40′ N.; 1° 14′ W.	58° 55′ N.; 1° 30′ W.	60	8/8/10	13/10/14	4	2	5	46	3	S. 10° W.	39, 48, 57
12c	59° 26′ N.; 4° 7′ W.	54° 26′ N.; 0° 58′ E.	27	19/8/10	27/ 8/14	4	0	8	322	22	S. 21° E.	—
14a	58° 15′ N.; 5° 55′ W.	58° 0′ N.; 5° 48′ W.	—	20/8/10	12/11/13	3	2	23	15	1	S. 14° E.	Minch.
40a	58° 6′ N.; 0° 15′ E.	58° 5′ N.; 0° 5′ E.	65	27/9/10	14/12/13	3	2	17	5	5	S. 79° W.	68
56c	56° 48′ N.; 1° 19′ E.	56° 15′ N.; 0° 10′ E.	50	11/2/11	3/ 2/15	3	11	23	51	4	S. 49° W.	100, 110
61a	58° 26′ N.; 0° 8′ W.	59° 20′ N.; 1° 10′ W	68	12/2/11	16/11/13	2	9	4	63	6	N. 31° W.	67, 58, 48
62c	58° 17′ N.; 1° 3′ W.	58° 57′ N.; 1° 00′ W.	76	12/2/11	1/ 8/14	3	5	20	40	3	N 2° E.	57, 66
62e	58° 17′ N.; 1° 3′ W.	57° 55′ N.; 0° 17′ W.	72	12/2/11	6/ 1/15	3	10	25	33	3	S. 48° E.	66, 77
63c	58° 8′ N.; 2° 0′ W.	57° 35′ N.; 1° 15′ W.	50	13/2/11	11/11/15	4	8	26	44	3	S. 41° E.	76
109a	59° 31′ N.; 0° 37′ E.	59° 20′ N.; 1° 00′ E.	68	19/3/11	31/12/12	1	9	12	17	3	S. 47° E.	50
112a	57° 31′ N.; 1° 12′ W.	56° 58′ N.; 1° 8′ W.	38	20/5/11	6/ 7/14	3	1	16	33	3	S. 3° E.	86
115b	58° 34′ N.; 0° 47′ E.	58° 45′ N.; 0° 32′ E.	80	24/5/11	29/11/13	2	6	5	13	1	N. 34° W.	59
125i	58° 26′ N.; 0° 8′ W.	58° 35′ N.; 1° 00′ W.	64	1/6/11	7/ 9/13	2	3	6	30	4	N. 71° W.	58, 67
		ADDITIONAL BOTTLES STRANDED ON THE COAST.										
11d	59° 40′ N.; 3° 3′ W.	Maywick, Shetland	Beach	19/8/10	10/ 3/15	4	6	19	70	—	Northerly	—
40c	58° 6′ N.; 0° 15′ E.	Sandwick ,,	,,	27/9/10	29/12/15	4	3	2	120	—	,,	—
10g	60° 40′ N.; 1° 27′ W.	Near Bergen, Norway	,,	15/8/10	3/12/13	3	3	17	350	—	—	—
13g	59° 14′ N.; 4° 57′ W.	—	,,	19/8/10	8/ 3/15	4	6	17	—	—	—	—
15a	57° 48′ N.; 8° 10′ W.	63° 25′ N.; 10° 24′ E.	,,	25/8/10	28/ 9/14	4	1	3	650	—	—	—
17c	57° 57′ N.; 8° 11′ W.	Havósund, Norway	,,	25/8/10	14/10/14	4	1	19	600	—	—	—
29d	58° 34′ N.; 0° 47′ E.	Dalmoen ,,	,,	10/9/10	3/ 6/14	3	8	24	—	—	—	—
31c	58° 17′ N.; 1° 3′ W.	Jaderen ,,	,,	10/9/10	26/ 5/14	3	8	16	—	—	—	—
31d	58° 17′ N.; 1° 3′ W.	65° 0′ N.; 12° 0′ E. (Bösolöholmen, Norway)	,,	10/9/10	26/ 1/14	3	4	16	500	—	—	—
36d	59° 30′ N.; 1° 0′ W.	62° 35′ N.; 6° 0′ E. (Near Aalesund, Norway)	,,	15/9/10	31/12/13	3	3	16	300	—	—	—
58d	57° 59′ N.; 0° 57′ E.	63° 25′ N.; 8° 0′ E.	,,	12/2/11	3/ 2/14	2	11	21	400	—	—	—
60b	58° 34′ N.; 0° 47′ E.	(Skonovaagen, Norway)	,,	12/2/11	10/12/13	2	9	29	—	—	—	—
70h	56° 22′ N.; 1° 33′ W	58° 50′ N.; 11° 12′ E.	,,	28/3/11	3/ 8/14	3	4	6	150	—	—	—

TABLE III.—THIRD EXPERIMENT.—BOTTOM DRIFT BOTTLES RECOVERED UP TO 31ST JANUARY 1916.

Reference No. of Card.	Position Cast out.	Position Recovered.	Depth of Water.	Date. Cast out.	Date. Recovered.	Days Adrift.	Distances between Positions.	Drift in 100 Days.	Direction, True.	Area.
			Fms.				Miles.			
13	58° 0′ N.; 1° 29′ W.	58° 27′ N.; 1° 40′ W.	50	11/4/14	13/ 4/14	2	28	—	N. 12° W.	66
15	58° 9′ N.; 1° 0′ W.	58° 8′ N.; 0° 55′ W.	63	11/4/14	1/10/14	174	3	2	S. 68° E.	67
16	58° 14′ N.; 0° 46′ W.	58° 16′ N.; 0° 58′ W.	67	11/4/14	31/ 7/14	111	7	6	N. 73° W.	67
49	59° 25′ N.; 1° 7′ W.	59° 35′ N.; 1° 0′ W.	68	16/4/14	28/10/14	195	10	5	N. 19° E.	48
64	60° 42′ N.; 0° 31′ W.	61° 3′ W.; 1° 0′ W.	75	21/4/14	20/12/15	639	25	4	N. 34° W.	22
67	58° 59′ N.; 2° 29′ W.	59° 1′ N.; 2° 17′ W.	41	28/4/14	31/ 7/14	94	6	6	N. 72° E.	56
72	58° 35′ N.; 1° 52′ W.	58° 17′ N.; 1° 40′ W.	50	28/4/14	14/10/14	169	19	11	S. 20° E.	57, 66
78	57° 14′ N.; 1° 36′ W.	57° 10′ N.; 1° 46′ W.	35	19/6/14	4/10/15	472	7	2	S. 53° W.	86
81	57° 19′ N.; 1° 5′ W.	57° 12′ N.; 0° 40′ W.	44	19/6/14	14/ 4/15	299	15	5	S. 62° E.	86, 87
120	57° 23′ N.; 1° 13′ W.	57° 25′ N.; 1° 13′ W.	60	25/6/14	4/ 7/14	9	2	—	N.	86
128	56° 54′ N.; 0° 43′ W.	56° 42′ N.; 0° 43′ W.	45	26/6/14	2/ 3/15	249	12	5	S.	98
129	56° 48′ N.; 0° 32′ W.	56° 45′ N.; 0° 33′ W.	47	26/6/14	27/ 9/14	62	3	5	S. 10° W.	98
136	56° 21′ N.; 0° 54′ W.	56° 18′ N.; 1° 12′ W.	37	26/6/14	14/ 7/14	18	10	—	S. 74° W.	109, 108
138	56° 6′ N.; 1° 0′ W.	56° 11′ N.; 0° 37′ W.	—	26/6/14	3/ 3/15	250	14	5	N. 22° E.	109
144	56° 13′ N.; 2° 10′ W.	56° 12′ N.; 2° 2′ W.	20	26/6/14	30/ 7/14	34	5	17	S. 80° E.	107
144	56° 13′ N.; 2° 10′ W.	56° 13′ N.; 2° 8′ W.	27	26/6/14	10/ 7/14	10	1	—	E.	107
188	60° 42′ N.; 0° 35′ W.	60° 41′ N.; 0° 38′ W.	55	11/6/14	29/ 9/14	110	2	2	S. 34° W.	22
189	61° 3′ N.; 0° 34′ W.	60° 58′ N.; 1° 4′ W.	64	12/6/14	25/10/14	135	15	11	S. 19° W.	22, 21
190	60° 57′ N.; 1° 19′ W.	61° 0′ N.; 1° 20′ W.	60	12/6/14	28/ 5/15	350	3	1	N. 27° W.	21
216	59° 13′ N.; 0° 19′ W.	59° 16′ N.; 0° 22′ W.	79	26/6/14	26/ 9/14	102	3	3	N. 27° W.	49
218	58° 58′ N.; 0° 0′ W.	58° 50′ N.; 1° 0′ W.	75	16/6/14	30/10/14	136	32	23	S. 75° W.	40
245	57° 40′ N.; 1° 10′ W.	57° 35′ N.; 1° 20′ W.	52	17/6/14	8/ 1/16	570	7	1	S. 43° W.	97
246	57° 30′ N.; 1° 17′ W.	57° 28′ N.; 1° 18′ W.	59	17/6/14	10/ 1/15	207	2	1	S. 14° W.	86
246	57° 30′ N.; 1° 17′ W.	57° 12′ N.; 1° 10′ W.	42	17/6/14	22/ 8/15	431	18	4	S. 14° E.	86
247	57° 30′ N.; 1° 19′ W.	57° 25′ N.; 1° 15′ W.	55	17/6/14	20/ 8/15	429	5	1	S. 24° E.	86
337	58° 26′ N.; 0° 8′ W.	58° 30′ N.; 0° 35′ W.	75	15/7/14	20/ 7/14	5	15	—	N. 74° W.	67
348	57° 12′ N.; 1° 27′ W.	57° 17′ N.; 1° 36′ W.	45	16/7/14	6/ 8/15	386	7	2	N. 45° W.	86
348	57° 12′ N.; 1° 27′ W.	57° 14′ N.; 1° 13′ W.	44	16/7/14	31/ 9/14	15	8	—	N. 75° E.	86
351	57° 6′ N.; 1° 5′ W.	57° 17′ N.; 1° 10′ W.	—	16/7/14	22/12/15	521	11	2	N. 14 W.	86
353	56° 44′ N.; 1° 33′ W.	56° 48′ N.; 1° 35′ W.	34	20/7/14	19/ 9/15	426	4	1	N. 16° W.	97
356	56° 2′ N.; 1° 47′ W.	55° 58′ N.; 1° 35′ W.	37	22/7/14	20/10/14	90	8	9	S. 59° E.	108, 118

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